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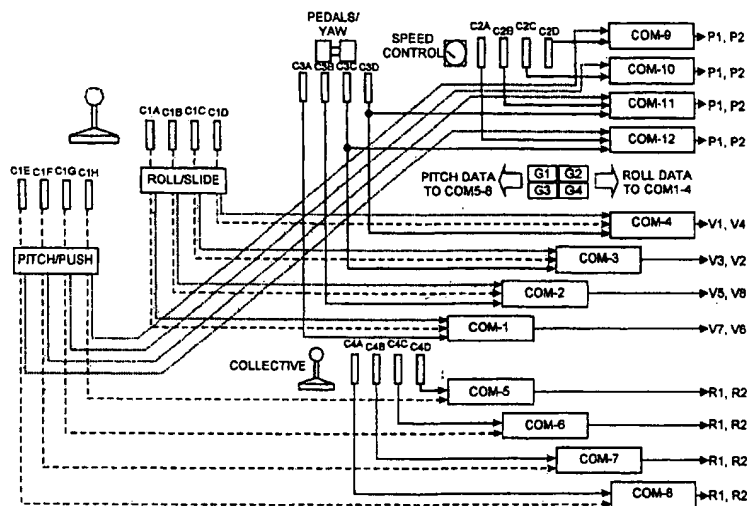
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(54) Title: **FLIGHT CONTROL SYSTEM FOR VTOL AIRCRAFT**



(57) Abstract: Flight control system including multiple control channels that each includes a vehicle sensor (C1 - C4) for monitoring a vehicle operational parameter, a computer (COM1 - COM12), and an actuator for controlling a vehicle control surface (V1 - V8), and multiple control groups that each groups a subset of the control channels and controls a different class of vehicle flight control elements, where in any of the control channels the computer receives a sensor reading and control the actuator in accordance with a predefined program appropriate for the reading, where each of the actuators partly controls a type of vehicle movement, where each of the actuators in any of the control groups controls their type of vehicle movement substantially in a mutually exclusive manner such that any of the actuators in any of the control groups may lose control power up to a predefined degree and continue to substantially maintain vehicle control in accordance with a predefined control measure.

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## Flight control system for VTOL aircraft.

### FIELD OF THE INVENTION

5           The present invention relates to flight control systems in general, and particularly to their use with VTOL (Vertical Take-Off and Landing) aircraft.

### BACKGROUND OF THE INVENTION

Many different types of VTOL aircraft have been proposed where the weight of  
10 the vehicle in hover is carried directly by rotors or propellers, with the axis of rotation perpendicular to the ground. One well known vehicle of this type is the conventional helicopter which includes a large rotor mounted above the vehicle fuselage. Other types of vehicles rely on propellers that are installed inside circular cavities, shrouds, ducts or other types of nacelle, where the propeller or rotor is not exposed, and where the flow of air takes  
15 place inside the circular duct. Most ducts have uniform cross-sections with the exit area (usually at the bottom of the duct when the vehicle is hovering) being similar to that of the inlet area (at the top of the duct). Some ducts, however, are slightly divergent, having an exit area that is larger than the inlet area, as this was found to increase efficiency and reduce the power required per unit of lift for a given inlet diameter. Some ducts have a wide inlet  
20 lip in order to augment the thrust obtained, especially in hover.

VTOL vehicles are usually more challenging than fixed wing aircraft in terms of stability and control. The main difficulty rises from the fact that, contrary to fixed wing aircraft which accelerate on the ground until enough airspeed is achieved on their flight surfaces, VTOL vehicles hover with sometimes zero forward airspeed. For these vehicles,  
25 the control relies on utilizing the rotors or propellers themselves, or the flow of air that they produce to create control forces and moments and forces around the vehicle's center of gravity (CG).

One method, which is very common in helicopters, is to mechanically change, by command from the pilot, the pitch of the rotating rotor blades both collectively and  
30 cyclically, and to modify the main thrust as well as moments and/or inclination of the propeller's thrust line that the propeller or rotor exerts on the vehicle. Some VTOL vehicles

using ducted or other propellers that are mounted inside the vehicle also employ this method of control. Some designers choose to change only the angle of all the blades using ducted or other propellers that are mounted inside the vehicle for this method of control. The angle of all the blades may be changed simultaneously (termed collective control) to  
5 avoid the added complexity of changing the angle of each blade individually (termed cyclic control). On vehicles using multiple fans which are relatively far from the CG, different collective control settings can be used on each fan to produce the desired control moments.

The disadvantage of using collective controls, and especially cyclic controls, lies in their added complexity, weight and cost. Therefore, a simple thrust unit that is also able  
10 to generate moments and side forces, while still retaining a simple rotor not needing cyclic blade pitch angle changes, has an advantage over the more complex solution. The main problem is usually the creation of rotational moments of sufficient magnitude required for control.

One traditional way of creating moments on ducted fans is to mount a discrete  
15 number of vanes at or slightly below the exit section of the duct. These vanes, which are immersed in the flow exiting the duct, can be deflected to create a side force. Since the vehicle's center of gravity is in most cases at a distance above these vanes, the side force on the vanes also creates a moment around the vehicle's CG.

However, one problem associated with vanes mounted at the exit of the duct in  
20 the usual arrangement as described above, is that even if these are able to create some moment in the desired direction, they cannot do so without creating at the same time a significant side force that has an unwanted secondary effect on the vehicle. For such vanes mounted below the vehicle's CG (which is the predominant case in practical VTOL vehicles), these side forces cause the vehicle to accelerate in directions which are usually  
25 counter-productive to the result desired through the generation of the moments by the same vanes, thereby limiting their usefulness on such vehicles.

The Chrysler VZ-6 VTOL flying car uses vanes on the exit side of the duct, together with a small number of very large wings mounted outside and above the duct inlet area.

However, in the VZ-6, the single wing and the discrete vanes were used solely for the purpose of creating a steady, constant forward propulsive force, and not for creating varying control moments as part of the stability and control system of the vehicle.

5 The Hornet unmanned vehicle developed by AD&D, also experimented with using either a single, movable large wing mounted outside and above the inlet, or, alternatively using a small number of vanes close to the inlet side. However these were fixed in angle and could not be moved in flight.

Another case that is sometimes seen is that of vanes installed radially from the center of the duct outwards, for the purpose of creating yawing moments (around the  
10 propeller's axis).

## SUMMARY OF THE INVENTION

The present invention provides a flight control system for aircraft, such as for a vehicle with a ducted fan propulsion system which also produces rotary moments and side  
15 forces for control purposes. The flight control system of the present invention is designed in a manner that will ensure the safety of the vehicle in event of a malfunction in any one of its channels and enable the flight to continue down to a safe landing.

## BRIEF DESCRIPTION OF THE DRAWINGS

20 The invention is herein described, by way of example only, with reference to the accompanying drawings, wherein:

Fig. 1 illustrates one form of VTOL aircraft vehicle useful in understanding the present invention;

Fig. 2 illustrates only one of the ducted fans in the aircraft of Fig. 1;

25 Fig. 3 is a sectional view along line III -- III of Fig. 2;

Fig. 4 is a diagram illustrating the positioning of the vanes of Fig. 3 in one direction to produce a lateral force in one direction.

Fig. 5 is a diagram illustrating the positioning of the vanes of Fig. 3 to produce a lateral force in the opposite direction.

30 Fig. 6 illustrates a modification in the construction of the vanes wherein each of the vanes is split into two halves, each half of all the vanes being separately pivotal from the

other half of all the vanes to produce a rotary moment force about the duct longitudinal axis;

Fig. 7 is a diagram illustrating the construction of one of the vanes and the manner for pivoting it;

5 Fig. 8 illustrates an alternative construction of one of the vanes and the manner for pivoting it;

Fig. 9 illustrates one arrangement that may be used for providing two cascades or assemblies of vanes at the inlet end of the duct of Fig. 9;

10 Fig. 10 illustrates another arrangement that may be used for providing two cascades or assemblies of vanes at the inlet end of the duct;

Fig. 11 illustrates a VTOL aircraft vehicle including a single ducted fan for propulsion and control purposes;

Fig. 12 is a view similar to that of Fig. 3 but illustrating the provision of a cascade or plurality of vanes also at the exit end of the duct;

15 Figs. 13a-13d illustrate various pivotal positions of the two cascades of vanes in the ducted fan of Fig. 12, and the forces produced by each such positioning of the vanes;

Fig. 14 is a top view diagrammatically illustrating another construction wherein the vanes extending across the inlet of the duct are divided into two groups together producing the desired net horizontal control force;

20 Figs. 15a and 15b diagrammatically illustrate the manner in which the desired net horizontal control force is produced by the vanes of Fig. 14;

Fig. 16 is a view corresponding to that of Fig. 14 but illustrating a variation in the vane arrangement for producing the desired net horizontal control force;

25 Fig. 17 illustrates a VTOL vehicle with two ducted fans useful in understanding the present invention;

Fig. 18 illustrates an alternative construction with four ducted fans;

Fig. 19 illustrates a construction similar to Fig. 17 with free propellers, i.e., unducted fans;

Fig. 20 illustrates a construction similar to Fig. 18 with free propellers;

Fig. 21 illustrates a construction similar to that of Fig. 17 but including two propellers, instead of a single propeller, mounted side-by-side in a single, oval shaped duct at each end of the vehicle;

5 Figs. 22a, 22b and 22c are side, top and rear views, respectively, illustrating another VTOL vehicle useful in understanding the present invention and including pusher propellers in addition to the lift-producing propellers;

Fig. 23 is a diagram illustrating the drive system in the vehicle of Figs. 22a – 22c;

10 Fig. 24 is a pictorial illustration of a vehicle constructed in accordance with Figs. 22a – 22c and 23;

Fig. 25a – 25d illustrate examples of various tasks and missions capable of being accomplished by the vehicle of Fig. 24;

Figs. 26a and 26b are side and top views, respectively, illustrating another VTOL vehicle constructed in accordance with the present invention;

15 Fig. 27 is a diagram illustrating the drive system in the vehicle of Figs. 26a and 26b;

Figs. 28a and 28b are side and top views, respectively, illustrating a VTOL vehicle constructed in accordance with any one of Figs. 22a – 27 but equipped with deployable stub wings, the wings being shown in these figures in their retracted stowed positions;

20 Figs. 28c and 28d are views corresponding to those of Figs. 28a and 28b but showing the stub wings in their deployed, extended positions;

Fig. 29 is a perspective rear view of a vehicle constructed in accordance with any one of Figs. 22a – 27 but equipped with a lower skirt for converting the vehicle to a hovercraft for movement over ground or water;

25 Fig. 30 is a perspective rear view of a vehicle constructed in accordance with any one of Figs. 22a – 23 but equipped with large wheels for converting the vehicle for ATV (all terrain vehicle) operation;

30 Figs. 31a-31e are a pictorial illustration of an alternative vehicle arrangement wherein the vehicle is relatively small in size, having the pilot's cockpit installed to one side of the vehicle. Various alternative payload possibilities are shown.

Fig. 32 is a pictorial illustration of a vehicle constructed typically in accordance with the configuration in Figs. 31a-31e but equipped with a lower skirt for converting the vehicle to a hovercraft for movement over ground or water.

Fig. 33 is a pictorial illustration of a cockpit control configuration, constructed and operative in accordance with a preferred embodiment of the present invention;

Fig. 34 is a simplified block diagram of a multi-channel flight control system, constructed and operative in accordance with a preferred embodiment of the present invention; and

Fig. 35 is a table summarizing control and effect in various flight modes, operative in accordance with a preferred embodiment of the present invention.

#### DESCRIPTION OF PREFERRED EMBODIMENTS

The vehicle illustrated in Fig. 1, and therein generally designated 2, is a VTOL aircraft including a frame or fuselage 3 carrying a ducted fan propulsion unit 4 at the front, and another similar propulsion unit 5 at the rear. The vehicle payload is shown at 6 and 7, respectively, on opposite sides of the fuselage, and the landing gear as shown at 8.

Figs. 2 and 3 more particularly illustrate the structure of propulsion unit 4, which is the same as propulsion unit 5. Such a propulsion unit includes a duct 10 carried by the fuselage 3 with the vertical axis 10a of the duct parallel to the vertical axis of the vehicle. Propeller 11 is rotatably mounted within the duct 10 about the longitudinal axis 10a of the duct. Nose 12 of the propeller faces upwardly, so that the upper end 13 of the duct constitutes the air inlet end, and the lower end 14 of the duct constitutes the exit end. As shown particularly in Fig. 3, the upper air inlet end 13 is formed with a funnel-shaped mouth to produce a smooth inflow of air into the duct 10, which air is discharged at high velocity through the exit end 14 of the duct for creating an upward lift force.

To provide directional control, the duct 10 is provided with a plurality of parallel, spaced vanes 15 pivotally mounted to, and across, the inlet end 13 of the duct. Each of the vanes 15 is pivotal about an axis 16 perpendicular to the longitudinal axis 10a of the duct 10 and substantially parallel to the longitudinal axis of the vehicle frame 2, to produce a desired horizontal control force in addition to the lift force applied to the vehicle by the movement of air produced by the propeller 11. Thus, as shown in Fig. 4, if the vanes

15 are pivoted in one direction about their respective axes, they produce a desired control force in the direction of the arrow F1 in Fig. 4; and if they are pivoted in the opposite direction, they produce a desired control force in the direction of the arrow F2 in Fig. 5. As shown in Fig. 3 (also Figs. 7, 8, 12), the vanes 15 are of a symmetric airfoil shape and are spaced from each other a distance approximately equal to the chord length of the vanes.

Fig. 6 illustrates a variation wherein each of the vanes 15, instead of being pivotally mounted as a unit for its complete length to produce the desired side control force is split into two half-sections, as shown at 15a and 15b in Fig. 6, with each half-section separately pivotal from the other half-section. Thus, all the half-sections 15a may be pivoted as a unit in one direction as shown by arrow D<sub>1</sub>, and all the half-sections 15b may be pivoted in the opposite direction as shown by arrow D<sub>2</sub>, to thereby produce any desired side force or rotary moment in addition to the lift force applied to the vehicle by the propeller.

As shown in Fig. 7, each of the vanes 15 is pivotally mounted about axis 16 passing through a mid portion of the vane. Fig. 8 illustrates a modification wherein each vane includes a fixed section 17, which constitutes the main part of the vane, and a pivotal section or flap 18 pivotally mounted at 19 to the trailing side of the fixed section. It will thus be seen that the pivotal section or flap 18 may be pivoted to any desired position in order to produce the desired control force in addition to the lift.

Fig. 9 illustrates a variation wherein the ducted fan (4 and/or 5 Fig. 1) includes a second plurality or cascade of parallel, spaced vanes, one of which is shown at 20, pivotally mounted to and across the inlet end 13 of the duct 10. Thus, each of the vanes 20 of the second plurality is closely spaced to the vanes 15 and is pivotal about an axis perpendicular to the pivotal axis of the vanes 15, as well as to the longitudinal axis 10a of the duct.

In the variation illustrated in Fig. 9, the two cascades of vanes 15, 20, are arranged in parallel, spaced planes. Fig. 10 illustrates a variation wherein the two cascades of vanes at the inlet end of the duct are intermeshed. For this purpose, each of the vanes 21 of the second plurality would be interrupted so as to accommodate the crossing vanes 15 of the first plurality, as shown in Fig. 10. Another possible arrangement would be to have the vanes of both cascades interrupted for purposes of intermeshing.

Fig. 11 illustrates a VTOL aircraft vehicle, therein generally designated 22, including a single ducted fan 24 carried centrally of its fuselage 23. Such a vehicle could

include the arrangement of vanes illustrated in either Fig. 9 or in Fig. 10 to provide the desired control forces and moments in addition to the lift forces. In such a vehicle, the payload may be on opposite sides of the central ducted fan 24, as shown at 25 and 26 in Fig. 11. The vehicle may also include other aerodynamic surfaces, such as rudders 27, 28 to provide steering and other controls.

Fig. 12 illustrates a further embodiment that may be included in either of the vehicles of Figs. 1 and 11 wherein the duct 10 also has a second plurality or cascade of parallel, spaced vanes, but in this case, the second plurality are pivotally mounted to and across the exit end 14 of the duct 10. Thus, as shown in Fig. 12, the duct 10 includes the first plurality or cascade of blades 15 mounted to and across the inlet end 13 of the duct, and a second plurality or cascade of blades 35 mounted to and across the exit end 14 of the duct 10, also perpendicular to the longitudinal axis of the duct and substantially parallel to the longitudinal axis of the vehicle frame. Each assembly or cascade 15, 35 of the vanes may be pivoted independently of the other to produce selected side forces or rotary moments about the duct's transverse axis 10b for pitch or roll control of the vehicle.

This is more clearly shown in the diagrams of Figs. 13a-13d. Thus, when the two cascades of vanes 15, 35, are pivoted in opposite directions, they produce a rotary moment about the transverse axis 10b of the duct 10 in one direction (e.g., counter-clockwise as shown in Fig. 13a); when they are pivoted in the same direction, they produce a side force in one direction (e.g. left) as shown in Fig. 13b when pivoted in opposite directions but opposite to the arrangement shown in Fig. 13a, they produce a rotary moment in the opposite clockwise direction as shown in Fig. 13c; and when they are pivoted in the same direction but opposite to that shown in Fig. 13b, they produce a side force in the opposite (e.g. right) direction, as shown in Fig. 13d.

Fig. 14 is a top view illustrating another construction of ducted fan propulsion unit, generally designated 1420, including a duct 1422 having a plurality of vanes 1424 extending across the inlet end of the duct. In this case, the vanes 1424 are divided into a first group of parallel vanes 1424a extending across one-half the inlet end of the duct 1422, and a second group of parallel vanes 1424b extending across the remaining half of the inlet end of the duct.

Fig. 14 also illustrates the nose 1426 of the propeller within the duct 1422. The propeller is rotatably mounted within the duct 1422 about the longitudinal axis of the duct, with the nose 1426 of the propeller centrally located at the air inlet end of the duct such that the air discharged at a high velocity through the opposite end of the duct creates an upward lift force.

As shown in Fig. 14, the first group of parallel vanes 1424a extending across one half of the inlet end of the duct 1422 are pivotal about axes 1425a at a predetermined acute angle  $\alpha$  with respect to the longitudinal axis 1420a of the vehicle frame and thereby of the direction of movement of the vehicle as shown by arrow 1427; and that the second group of parallel vanes extending across the remaining half of the inlet end of the duct are pivotal about axes 1425b at the same predetermined angle  $\alpha$ , but in the opposite direction, with respect to the longitudinal axis 1420a of the vehicle frame. The two groups of vanes 1424a, 1424b are selectively pivotal to produce a desired net horizontal control force in addition to the lift force applied to the vehicle.

The foregoing operations are illustrated in the diagrams of Figs. 15a and 15b. Both Fig. 15a and 15b illustrate the control forces generated when the vehicle includes two ducted fan propulsion units 1420, 1430, at the opposite ends of the vehicle and coaxial with the vehicle longitudinal axis 1420a. It will be appreciated that comparable forces are produced when the vehicle is equipped with only one ducted fan propulsion unit shown in Fig. 14.

Fig. 15a illustrates the condition wherein the two groups of vanes 1424a, 1424b are pivoted to equal angles about their respective axes 1425a, 1425b. The vanes thus produce, in addition to the lift force, control forces of equal magnitude and angles on opposite sides of the vehicle longitudinal axis 1420a, so as to produce a net force, shown at  $F_a$ , coaxial with the vehicle longitudinal axis 1420a.

The two groups of vanes 1434a, 1434b of the rear propulsion unit 1430 are pivotal in the same manner about their respective pivotal axes 1435a, 1435b, and thereby produce a net force  $F_a$  also coaxial with the vehicle longitudinal axis 1420a.

Fig. 15b illustrates a condition wherein the two groups of vanes 1424a, 1424b in the fore propulsion unit 1420, and the two groups of vanes 1434a, 1434b in the aft propulsion unit 1430, are pivoted about their respective axes to unequal angles, thereby

producing net side forces  $F_b$  at an angle to the vehicle longitudinal axis 1420a. Thus, by controlling the pivot angles of the vanes 1424a, 1424b and 1434a, 1434b about their respective pivotal axes, a net control force may be generated as desired in the plane of the vanes.

5            Fig. 16 illustrates a ducted fan propulsion unit, generally designated 40, also including two groups of vanes 1444a, 1444b, extending across one-half of the inlet of the duct 1442 and pivotally mounted about axes 1445a, 1445b at a predetermined angle, (e.g., 45°) to the longitudinal axis 1440a of the vehicle. In this case, however, the vanes 1444a, 1444b are oriented in the forward direction, rather than in the aft direction as in Fig. 14, but  
10    the operation, and the forces generated by the vanes, are basically the same as described above with respect to Figs. 14, 15a, 15b.

          It will be appreciated that any of the foregoing arrangements may be used in any of the above-described air vehicles to produce the desired control forces in addition to the lift forces. The vanes are not intended to block air flow, but merely to deflect air flow to  
15    produce the desired control forces. Accordingly, in most applications the vanes would be designed to be pivotal no more than 15° in either direction, which is the typical maximum angle attainable before flow separation.

          Since the control forces and moments are generated by horizontal components of the lift forces on the vanes themselves, the vanes should preferably be placed on the  
20    intake side of the propeller as far from the center of gravity of the vehicle as possible for creating the largest attainable moments. The same applies if vanes are provided on the axis side of the ducts.

          Fig. 17 illustrates an alternative vehicle construction in accordance with the present invention. In Fig. 17, a vehicle, generally designated 1710, includes a fuselage 1711  
25    having a longitudinal axis LA and a transverse axis TA. Vehicle 1710 further includes two lift-producing propellers 1712a, 1712b carried at the opposite ends of the fuselage 1711 along its longitudinal axis LA and on opposite sides of its transverse axis TA. Lift-producing propellers 1712a, 1712b are ducted fan propulsion units extending vertically through the fuselage and rotatable about vertical axes to propel the air downwardly and  
30    thereby to produce an upward lift.

Vehicle 1710 further includes a pilot's compartment 1713 formed in the fuselage 1711 between the lift-producing propellers 1712a, 1712 and substantially aligned with the longitudinal axis LA and transverse axis TA of the fuselage. The pilot's compartment 1713 may be dimensioned so as to accommodate a single pilot or two (or more) pilots, as shown, for example, in Fig. 22a.

Vehicle 1710 illustrated in Fig. 17 further includes a pair of payload bays 1714a, 1714b formed in the fuselage 1711 laterally on the opposite sides of the pilot's compartment 1713 and between the lift-producing propellers 1712a, 1712b. The payload bays 1714a, 1714b shown in Fig. 17 are substantially flush with the fuselage 1711, as will be described more particularly below with respect to Figs. 22a – 22c and the pictorial illustration in Figs. 25a – 25d. Also described below, particularly with respect to the pictorial illustrations of Figs. 25a – 25d, are the wide variety of tasks and missions capable of being accomplished by the vehicle when constructed as illustrated in Fig. 17 (and in the later illustrations), and particularly when provided with the payload bays corresponding to 14a, 14b of Fig. 17.

Vehicle 1710 illustrated in Fig. 17 further includes a front landing gear 1715a and a rear landing gear 1715b mounted at the opposite ends of its fuselage 1711. In Fig. 17 the landing gears are non-retractable, but could be retractable as in later described embodiments. Aerodynamic stabilizing surfaces may also be provided, if desired, as shown by the vertical stabilizers 1716a, 1716b carried at the rear end of fuselage 1711 on the opposite sides of its longitudinal axis LA.

Fig. 18 illustrates another vehicle construction in accordance with the present invention. In the vehicle of Fig. 18, therein generally designated 1820, the fuselage 1821 is provided with a pair of lift-producing propellers on each side of the transverse axis of the fuselage. Thus, as shown in Fig. 18, the vehicle includes a pair of lift-producing propellers 1822a, 1822b at the front end of the fuselage 1821, and another pair of lift-producing propellers 1822c, 1822d at the rear end of the fuselage. The lift-producing propellers 1822a – 1822d shown in Fig. 18 are also ducted fan propulsion units. However, instead of being formed in the fuselage 1821, they are mounted on mounting structures 1821a – 1821d to project laterally of the fuselage.

Vehicle 1820 illustrated in Fig. 18 also includes the pilot's compartment 1823 formed in the fuselage 1821 between the two pairs of lift-producing propellers 1822a, 1822b and 1822c, 1822d, respectively. As in the case of the pilot's compartment 1713 in Fig. 17, the pilot's compartment 1823 in Fig. 18 is also substantially aligned with the longitudinal axis LA and transverse axis TA of the fuselage 1821.

Vehicle 1820 illustrated in Fig. 18 further includes a pair of payload bays 1824a, 1824b formed in the fuselage 1821 laterally of the pilot's compartment 1823 and between the two pairs of lift-producing propellers 1822a – 1822d. In Fig. 18, however, the payload bays are not formed integral with the fuselage, as in Fig. 17, but rather are attached to the fuselage so as to project laterally on opposite sides of the fuselage. Thus, payload bay 1824a is substantially aligned with the lift-producing propellers 1822a, 1822c on that side of the fuselage; and payload bay 1824b is substantially aligned with the lift-producing propellers 1822b and 1822d at that side of the fuselage.

Vehicle 1820 illustrated in Fig. 18 also includes a front landing gear 1825a and a rear landing gear 1825b, but only a single vertical stabilizer 1826 at the rear end of the fuselage aligned with its longitudinal axis. It will be appreciated however, that vehicle 20 illustrated in Fig 2 could also include a pair of vertical stabilizers, as shown at 1716a and 1716b in Fig. 17, or could be constructed without any such aerodynamic stabilizing surface.

Fig. 19 illustrates a vehicle 1930 also including a fuselage 1931 of a very simple construction having a forward mounting structure 1931a for mounting the forward lift-producing propeller 1932a, and a rear mounting structure 1931b for mounting the rear lift-producing propeller 1932b. Both propellers are unducted, i.e., free, propellers. Fuselage 1931 is formed centrally thereof with a pilots compartment 1933 and carries the two payload bays 1934a, 1934b on its opposite sides laterally of the pilot's compartment.

Vehicle 1930 illustrated in Fig. 19 also includes a front landing gear 1935a and a rear landing gear 1935b, but for simplification purposes, it does not include an aerodynamic stabilizing surface corresponding to vertical stabilizers 1716a, 1716b in Fig. 17.

Fig. 20 illustrates a vehicle, generally designated 2040, of a similar construction as in Fig. 18 but including a fuselage 2041 mounting a pair of unducted propellers 2042a, 2042b at its front end, and a pair of unducted propellers 2042c, 2042d at its rear end by

means of mounting structures 2041a – 2041d, respectively. Vehicle 2040 further includes a pilot's compartment 2043 centrally of the fuselage, a pair of payload bays 2044a, 2044b laterally of the pilot's compartment, a front landing gear 2045a, a rear landing gear 2045b, and a vertical stabilizer 2046 at the rear end of the fuselage 2041 in alignment with its longitudinal axis.

Fig. 21 illustrates a vehicle, generally designated 2150, including a fuselage 2151 mounting a pair of lift-producing propellers 2152a, 2152b at its front end, and another pair 2152c, 2152d at its rear end. Each pair of lift-producing propellers 2152a, 2152b and 2152c, 2152d is enclosed within a common oval-shaped duct 2152e, 2152f at the respective end of the fuselage.

Vehicle 2150 illustrated in Fig. 21 further includes a pilot's compartment 2153 formed centrally of the fuselage 2151, a pair of payload bays 2154a, 2154b laterally of the pilot's compartment 2153, a front landing gear 2155a, a rear landing gear 2155b, and vertical stabilizers 2156a, 2156b carried at the rear end of the fuselage 2151.

Figs. 22a, 22b and 22c are side, top and rear views, respectively, of another vehicle constructed in accordance with the present invention. The vehicle illustrated in Figs. 22a – 22c, therein generally designated 2260, also includes a fuselage 2261 mounting a lift-producing propeller 2262a, 2262b at its front and rear ends, respectively. The latter propellers are preferably ducted units as in Fig. 17.

Vehicle 2260 further includes a pilot's compartment 2263 centrally of the fuselage 2261, a pair of payload bays 2264a, 2264b laterally of the fuselage and of the pilot's compartment, a front landing gear 2265a, a rear landing gear 2265b, and a stabilizer, which, in this case, is a horizontal stabilizer 2266 extending across the rear end of the fuselage 2261.

Vehicle 2260 illustrated in Figs. 22a – 22c further includes a pair of pusher propellers 2267a, 2267b, mounted at the rear end of the fuselage 2261 at the opposite ends of the horizontal stabilizer 2266. As shown particularly in Fig. 22c the rear end of the fuselage 2261 is formed with a pair of pylons 2261a, 2261b, for mounting the two pusher propellers 2267a, 2267b, together with the horizontal stabilizer 2266.

The two pusher propellers 2267a, 2267b are preferably variable-pitch propellers enabling the vehicle to attain higher horizontal speeds. The horizontal stabilizer 2266 is used

to trim the vehicle's pitching moment caused by the ducted fans 2262a, 2262b, thereby enabling the vehicle to remain horizontal during high speed flight.

Each of the pusher propellers 2267a, 2267b is driven by an engine enclosed within the respective pylon 2261a, 2261b. The two engines are preferably turbo-shaft engines. Each pylon is thus formed with an air inlet 2268a, 2268b at the forward end of the  
5 respective pylon, and with an air outlet (not shown) at the rear end of the respective pylon.

Fig. 23 schematically illustrates the drive within the vehicle 2360 for driving the two ducted fans 2362a, 2362b as well as the pusher propellers 2367a, 2367b. The drive system, generally designated 2370, includes two engines 2371, 2371b, each incorporated in  
10 an engine compartment within one of the two pylons 2361a, 2361b. Each engine 2371a, 2371b, is coupled by an over-running clutch 2372a, 2372b, to a gear box 2373a, 2373b coupled on one side to the respective thrust propeller 2367a, 2367b, and on the opposite side to a transmission for coupling to the two ducted fans 2362a, 2362b at the opposite ends of the fuselage. Thus, as schematically shown in Fig. 23, the latter transmission  
15 includes additional gear boxes 2374a, 2374b coupled to rear gear box 2375b for driving the rear ducted fan 2362b, and front gear box 2375a for driving the front ducted fan 2362b.

Fig. 24 pictorially illustrates an example of the outer appearance that vehicle 2360 may take.

In the pictorial illustration of Fig. 24, those parts of the vehicle which  
20 correspond to the above-described parts in Figs. 22a – 22c are identified by the same reference numeral suffixes in order to facilitate understanding. Fig. 24, however, illustrates a number of additional features which may be provided in such a vehicle.

Thus, as shown in Fig. 24, the front end of the fuselage 2261 may be provided with a stabilized sight and FLIR (Forward Looking Infra-Red) unit, as shown at 2481, and  
25 with a gun at the forward end of each payload bay, as shown at 2482. In addition, each payload bay may include a cover 2483 deployable to an open position providing access to the payload bay, and to a closed position covering the payload bay with respect to the fuselage 2261.

In Fig. 24, cover 2483 of each payload bay is pivotally mounted to the fuselage  
30 2261 along an axis 2484 parallel to the longitudinal axis of the fuselage at the bottom of the respective bay. The cover 2483, when in its closed condition, conforms to the outer surface

of the fuselage 2261 and is flush therewith. When the cover 2483 is pivoted to its open position, it serves as a support for supporting the payload, or a part thereof, in the respective payload bay.

The latter feature is more particularly shown in Figs. 25a – 25d which illustrate various task capabilities of the vehicle as particularly enabled by the pivotal covers 2583 for the two payload bays. Thus, Fig. 25a illustrates the payload bays used for mounting or transporting guns or ammunition 2585a; Fig. 25b illustrates the use of the payload bays for transporting personnel or troops 2585b; Fig. 25c illustrates the use of the payload bays for transporting cargo 2585c; and Fig. 25d illustrates the use of the payload bays for evacuating wounded 2585d. Many other task or mission capabilities will be apparent.

Figs. 26a and 26b are side and top views, respectively, illustrating another vehicle, generally designated 90, of a slightly modified construction from vehicle 2260 described above. Thus, vehicle 90 illustrated in Figs. 26a and 26b also includes a fuselage 91, a pair of ducted-fan type lift-producing propellers 92a, 92b at the opposite ends of the fuselage, a pilot's compartment 93 centrally of the fuselage, and a pair of payload bays 94a, 94b laterally of the pilot's compartment 93. Vehicle 90 further includes a front landing gear 95a, a rear landing gear 95b, a horizontal stabilizer 96, and a pair of pusher propellers 97a, 97b, at the rear end of fuselage 91.

Fig. 27 schematically illustrates the drive system in vehicle 90. Thus as shown in Fig. 27, vehicle 90 also includes two engines 101a, 101b for driving the two ducted fans 92a, 92b and the two pusher propellers 97a, 97b, respectively, as in vehicle 2260. However, whereas in vehicle 2260 the two engines are located in separate engine compartments in the two pylons 2261a, 2261b, in vehicle 90 illustrated in Figs. 26a and 26b both engines are incorporated in a common engine compartment, schematically shown at 100 in Fig. 26a, underlying the pilot's compartment 93. The two engines 101a, 101b (Fig. 27), may also be turbo-shaft engines as in Fig. 23. For this purpose, the central portion of the fuselage 91 is formed with a pair of air inlet openings 98a, 98b forward of the pilot's compartment 93, and with a pair of air outlet openings 99a, 99b rearwardly of the pilot's compartment.

As shown in Fig. 27, the two engines 101a, 101b drive, via the over-running clutches 102a, 102b, a pair of hydraulic pumps 103a, 103b which, in turn, drive the drives 104a, 104b of the two pusher propellers 97a, 97b. The two engines 101a, 101b are further

coupled to a drive shaft 105 which drives the drives 106a, 106b of the two ducted fans 92a, 92b, respectively.

Figs. 28a – 28d illustrate another vehicle, therein generally designated 110, which is basically of the same construction as vehicle 2260 described above with respect to Figs. 22a – 22c, 23, 24 and 25a – 25d; to facilitate understanding, corresponding elements are therefore identified by the same reference numeral suffixes. Vehicle 110 illustrated in Figs. 28a – 28d, however, is equipped with two stub wings, generally designated 111a, 111b, each pivotally mounted to the fuselage 2861, under one of the payload bays 2864a, 2864b, to a retracted position shown in Figs. 28a and 28b, or to an extended deployed position shown in Figs. 28c and 28d for enhancing the lift produced by the ducted fans 2262a, 2262b. Each of the stub wings 111a, 111b is actuated by an actuator 112a, 112b driven by a hydraulic or electrical motor (not shown). Thus, at low speed flight, the stub wings 111a, 111b, would be pivoted to their stowed positions as shown in Figs. 28a and 28b; but at high speed flight, they could be pivoted to their extended or deployed positions, as shown in Figs. 28c and 28d, to enhance the lift produced by the ducted fans 2861a, 2861b. Consequently, the blades in the ducted fans would be at low pitch producing only a part of the total lift force.

The front and rear landing gear, shown at 115a and 115b, could also be pivoted to a stowed position to enable higher speed flight, as shown in Figs. 28c and 28d. In such case, the front end of the fuselage 2861 would preferably be enlarged to accommodate the landing gear when in its retracted condition. Vehicle 110 illustrated in Figs. 28a – 28d may also include ailerons, as shown at 116a, 116b (Fig. 28d) for roll control.

Fig. 29 illustrates how the vehicle, such as vehicle 2260 illustrated in Figs. 22a – 22d, may be converted to a hovercraft for traveling over ground or water. Thus, the vehicle illustrated in Fig. 29, and therein generally designated 2920, is basically of the same construction as described above with respect to Figs. 22a – 22d, and therefore corresponding parts have been identified with the same reference numeral suffixes. In vehicle 2920 illustrated in Fig. 29, however, the landing gear wheels (65a, 2965b, Figs. 22a – 22d) have been removed, folded, or otherwise stowed, and instead, a skirt 121 has been applied around the lower end of the fuselage 2961. The ducted fans 2962a, 2962b, may be operated at very low power to create enough pressure to cause the vehicle to hover over

the ground or water as in hovercraft vehicles. The variable pitch pusher propellers 2967a, 2967b would provide forward or rear movement, as well as steering control, by individually varying the pitch, as desired, of each propeller.

Vehicles constructed in accordance with the present invention may also be used  
5 for movement on the ground. Thus, the front and rear wheels of the landing gears can be driven by electric or hydraulic motors included within the vehicle.

Fig. 30 illustrates how such a vehicle can also be used as an ATV (all terrain vehicle). The vehicle illustrated in Fig. 30, therein generally designated 130, is basically of the same construction as vehicle 2260 illustrated in Figs. 22a – 22d, and therefore  
10 corresponding parts have been identified by the same reference numeral suffixes to facilitate understanding. In vehicle 130 illustrated in Fig. 30, however, the two rear wheels of the vehicle are replaced by two (or four) larger ones, bringing the total number of wheels per vehicle to four (or six). Thus, as shown in Fig. 30, the front wheels (e.g., 2965a, Fig. 22c) of the front landing gear are retained, but the rear wheels are replaced by two larger wheels  
15 135a (or by an additional pair of wheels, not shown), to enable the vehicle to traverse all types of terrain.

When the vehicle is used as an ATV as shown in Fig. 30, the front wheels 2965a or rear wheels would provide steering, while the pusher propellers 2967a, 2967b and main lift fans 2962a, 2962b would be disconnected but could still be powered-up for take-  
20 off if so desired. The same applies also with respect to the hovercraft version illustrated in Fig. 29.

It will thus be seen that the invention thus provides a utility vehicle of a relatively simple structure which is capable of performing a wide variety of VTOL functions, as well as many other tasks and missions, with minimum changes in the vehicle to  
25 convert it from one task or mission to another.

Figs. 31a-31e are pictorial illustrations of alternative vehicle arrangements where the vehicle is relatively small in size, having the pilot's cockpit installed to one side of the vehicle. Various alternative payload possibilities are shown.

Fig. 31a shows the vehicle in its basic form, with no specific payload installed.  
30 The overall design and placement of parts of the vehicle are similar to those of the 'larger' vehicle described in Fig. 24. with the exception of the pilot's cockpit, which in the

arrangement of Fig. 31a takes up the space of one of the payload bays created by the configuration shown in Fig. 24. The cockpit arrangement of Fig. 31a frees up the area taken up by the cockpit in the arrangement of Fig. 8 for use as an alternative payload area, increasing the total volume available for payload on the opposite side of the cockpit. It is appreciated that the mechanical arrangement of engines, drive shafts and gearboxes for the vehicle of Fig. 31a. may be that described with reference to Fig. 23.

Fig. 31b illustrates how the basic vehicle of Fig. 31a may be used to evacuate a patient. The single payload bay is optionally provided with a cover and side door which protect the occupants, and which may include transparent areas to enable light to enter. The patient lies on a stretcher which is oriented predominantly perpendicular to the longitudinal axis of the vehicle, and optionally at a slight angle to enable the feet of the patient to clear the pilot's seat area and be moved fully into the vehicle despite its small size. Space for a medical attendant is provided, close to the outer side of the vehicle.

Fig. 31c shows the vehicle of Fig. 31b with the cover and side door closed for flight.

Fig. 31d illustrates how the basic vehicle of Fig. 31a may be used to perform various utility operations such as electric power-line maintenance. In the example shown in Fig. 31d, a seat is provided for an operator, facing outwards towards an electric power-line. For illustration purposes, the operator is shown attaching plastic spheres to the line using tools. Uninstalled sphere halves and additional equipment may be carried in the open space behind the operator. Similar applications may include other utility equipment, such as for bridge inspection and maintenance, antenna repair, window cleaning, and other applications. One very important mission that the utility version of Fig. 31d could perform is the extraction of survivors from hi-rise buildings, with the operator assisting the survivors to climb onto the platform while the vehicle hovers within reach.

Fig. 31e illustrates how the basic vehicle of Fig. 31a may be used to carry personnel in a comfortable closed cabin, such as for commuting, observation, performing police duties, or any other purpose.

Fig. 32 is a pictorial illustration of a vehicle constructed typically in accordance with the configuration in Fig. 31 but equipped with a lower, flexible skirt for converting the vehicle to a hovercraft for movement over ground or water. While the vehicle shown in

Fig. 32 is similar to the application of Fig. 31e, it should be mentioned that a skirt can be installed on any of the applications shown in Fig. 31.

While Figs. 31a-32 show a vehicle having a cockpit on the left hand side and a payload bay to the right hand side, it is appreciated that alternative arrangements are possible, such as where the cockpit is on the right hand side and the payload bay is on the left hand side. All the descriptions provided in Figs. 31a-32 apply also to such an alternative configuration.

Fig. 33 shows a cockpit control configuration that may be used in any of the various vehicle configurations of the present invention described herein.

Reference is now made to Fig. 34, which is a simplified block diagram of a multi-channel flight control system, constructed and operative in accordance with a preferred embodiment of the present invention. The various vane-controlled vehicle configurations of the present invention are preferably equipped with the multi-channel flight control system of Fig. 34, or portions thereof as applicable, although it is appreciated that aspects of the system of Fig. 34 that do not relate to vane control may be applied to non-vane-controlled vehicles. The flight control system of the present invention is designed in a manner that will ensure the safety of the vehicle in event of a malfunction in any one of its channels and enable the flight to continue down to a safe landing. In order to facilitate this feature, the system is configured as a Fly-By-Wire system, separated into channels, with each having its own cockpit controls sensors, computer, actuator and control surfaces or variable pitch rotor/propeller blades where applicable. Each vehicle control function preferably has a control power reserve that enables the vehicle to be adequately controllable even if some control power is lost due to malfunction or a runaway condition in one of its channels. Separate vehicle position, rate and acceleration sensors together with altitude and airspeed data sensors are used to generate data on the vehicle's flight state.

It will be appreciated that the number of sensors, computers and channels shown in Fig. 34 may vary, provided that each of the vehicle's axes is provided multiple control paths such that loss of any given control path, while resulting in the path's controlled element being unable to perform its function, does not influence the remaining paths/channels on the same axis from continuing to perform their duties as required.

As can be seen in Fig. 34, the control system is divided into three main groups of controls:

- Control of the blades pitch angle on both main lift rotors;
- Control of all aerodynamic vanes installed on the vehicle in the entrance plane as well as the exit plane of both main lift rotors; and
- Control of the blades pitch angle on both aft mounted pusher propellers, such as may be particularly seen in Figs. 31a-31e.

Each group of controls features four separate channels / paths which include 4 cockpit controls position sensors (e.g. potentiometers, LVDTs, RVDTs), 4 control computers, and 4 actuators, each powering  $\frac{1}{4}$  of the control mechanisms (such as vanes) installed on the vehicle. In the case of actuators for rotor / propeller blade pitch change, each actuator will have four separate movement channels, each responsible for  $\frac{1}{4}$  of the total movement available for full control of said rotor or propeller.

The various control paths are shown in Fig. 34 by lines ending with arrows. Solid lines represent control paths that are constant throughout the flight envelope. Dashed lines represent paths that operate at high speed (cruise) flight, and dotted lines represent paths that are active during hover and Low Speed Maneuver (LSM) flight.

Logical switching, or, alternatively, continuous gain scheduling, is used to transition between LSM to cruise and vice versa. These switching modules are shown as rectangles marked as S1, S2.

Also shown in Fig. 34 are:

- |    |              |   |
|----|--------------|---|
| *  | COM1-COM12   | Flight control computers  |
| *  | P1,P2        | Pusher propellers   |
| *  | R1,R2        | Main lift rotors  |
| 25 | * V1-V8      | 8 segments of control vanes   |
|    | * C1-C4; a-h | Controls position sensors   |
| 30 | * G1-G4      | Four vehicle inertial position, rate and acceleration, altitude and airspeed sensors. Additional sensors such as, but not limited to, GPS, radar altimeters, millimeter wave radars may be added. |

Operation of the control system of Fig. 34 is now described with respect to the main lift rotors. Control of the pitch of the blades on both main lift rotors is accomplished by four separate computers (nos. 5-8). Each computer reads independently the position of the collective control, as well as the longitudinal stick position. Each computer also reads  
5 information on the vehicle's inertial position, rate and acceleration, altitude and airspeed from one of the four inertial position, rate and acceleration, altitude and airspeed sensors installed in the vehicle. Each computer commands  $\frac{1}{4}$  of the available travel of each of the two blade pitch change actuators connected to the main lift rotors. When the vehicle is in LSM mode, the information on the longitudinal stick position does not come into play in the  
10 main lift rotors control system. As the vehicle's motion becomes more "cruise" oriented, and less "LSM" oriented, each of the four computers, operating separately from each other, will switch or modify the gain associated with the reading on the position sensors attached to the pilot's controls in order to obtain the desired effect on the rotors. The software governing the operation of each computer, and especially the gain scheduling associated  
15 with the mode transitions in flight, may employ conventional techniques, or may be based on Fuzzy Logic / Neural computation methods.

Due to the above arrangement, a failure of one channel of the four will merely result in the main lift rotors not being able to change their blade pitch angles through more than  $\frac{3}{4}$  of their overall range. It will be appreciated that in event of a runaway malfunction,  
20 half of the normal travel will still be available. It will be further appreciated by analyzing the overall behavior of the vehicle that sufficient control is still available for carrying out a controlled descent to a landing.

Operation of the control system of Fig. 34 is now described with respect to control of the vehicle's aerodynamic vane surfaces. In an exemplary configuration a vehicle  
25 has 300 vanes powered by 8 separate actuators in a manner similar to that which is required for rotor blade pitch change. However, here each actuator moves its own set of vanes through the total useful range of movement of the vanes, such as 10 degrees to each side and as dictated by aerodynamic considerations.

Operation of the control system of Fig. 34 is now described with respect to  
30 control of the vehicle's pusher propellers. Control of the vehicles pusher propellers is similar to that of the main lift rotors. However, it will be appreciated that since the pusher

propellers are not critical to the controllability of the vehicle and its ability to perform a safe landing, the redundancy provided to the pusher propellers may be reduced, such as to two control channels instead of the four-channel arrangement shown for the other control groups.

5           Operation of the control system of Fig. 34 is now described with respect to control of the vehicle's inertial and other sensors. In the system of Fig. 34, four separate inertial position, rate and acceleration, altitude and airspeed sensors are installed. However, any of the control channels may share data generated on common sensor units. Thus, any error or malfunction of one sensor inside one of the four sensor packages may affect all  
10   three groups of controls: main rotors, vanes and pusher propellers. The design of the vehicle should be sufficiently robust enough so that any "crippling" of all modes of control, while not causing a hazardous situation with any of the controls separately, will still not pose a threat to the vehicle's safety when, as a result of one sensor malfunction, all three control groups are crippled or weakened simultaneously. Alternatively, additional sensor  
15   packages or individual sensors may be added as desired.

Fig. 35 shows a table summarizing the effect that each control has on the vehicle in two different flight conditions: hover and LSM (Low Speed Maneuver), and normal cruise flight.

It is appreciated that the various control surfaces may be divided into more or  
20   fewer sections than the four sections shown in Fig. 34, each independently controlled by a separate control path. It is also appreciated that each computer may control more than one control path of the vehicle, provided that each control path relates to a different type of vehicle control, such as pitch and yaw.

While the invention has been described above particularly with respect to air  
25   vehicles, it will be appreciated that the invention, or various aspects of the invention as described above, can also be advantageously used with other types of aircraft control, such as by providing the control path redundancy described in Fig. 34 to collective and cyclic control mechanisms, tail rotor controls, or any other types of controls typically found in other fixed-wing or rotory-wing aircraft.

30           Accordingly, while the invention has been described with respect to several preferred embodiments, it will be understood that these are set forth merely for purposes of

example, and that many other variations, modifications and applications of the invention may be made.

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## CLAIMS

What is claimed is:

1. A multi-channel flight control system comprising:  
a plurality of control channels, each control channel comprising:  
5 a vehicle sensor operative to monitor an operational parameter of said vehicle;  
a computer; and  
an actuator operative to control a control surface of said vehicle; and  
a plurality of control groups, each control group operative to group a subset of  
10 said control channels and control a different class of vehicle flight control elements,  
wherein in any of said control channels said computer is operative to receive a sensor reading and control said actuator in accordance with a predefined program appropriate for said reading,  
wherein each of said actuators is operative to partly control a type of vehicle  
15 movement, and  
wherein each of said actuators in any of said control groups control their type of vehicle movement substantially in a mutually exclusive manner such that any of said actuators in any of said control groups may lose control power up to a predefined degree and continue to substantially maintain vehicle control in accordance with a predefined  
20 control measure.
2. A system according to claim 1 wherein any of said actuators is operative to control a control surface.
- 25 3. A system according to claim 1 wherein any of said actuators is operative to control a propulsion element
4. A system according to claim 1 wherein said sensor is a cockpit control position sensor.

5. A system according to claim 1 wherein each of said classes of vehicle flight control elements control a different vehicle axis.

5 6. A system according to claim 1 wherein a computer in any of said control groups controls an actuator in any other of said control groups.

7. A system according to claim 5 wherein a computer in any of said control groups controls an actuator in any other of said control groups.

10

8. A system according to claim 1 wherein a first of said control groups controls blade pitch angle on main lift rotors of said vehicle, wherein a second of said control groups controls aerodynamic vanes of said vehicle, and wherein a third of said control groups controls blades pitch angle on aft mounted pusher propellers of said vehicle.

15

9. A system according to claim 1 wherein any of said control groups controls an aerodynamic vane of said vehicle.

10. A system according to claim 1 wherein different sets of said control paths are  
20 operative during high-speed flight and low-speed flight.

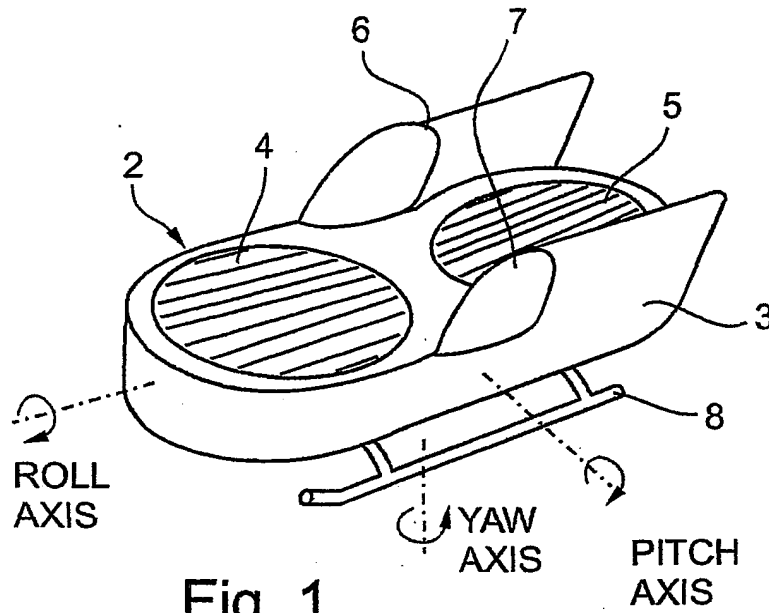


Fig. 1

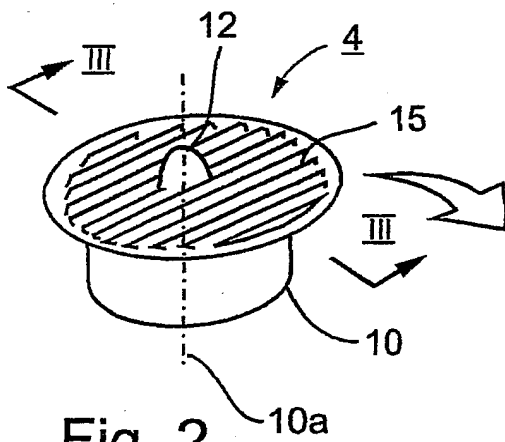


Fig. 2

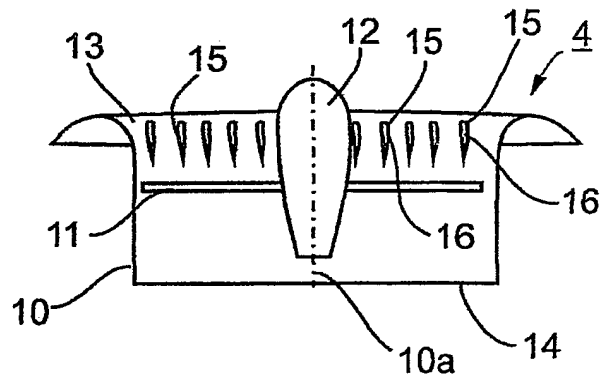


Fig. 3

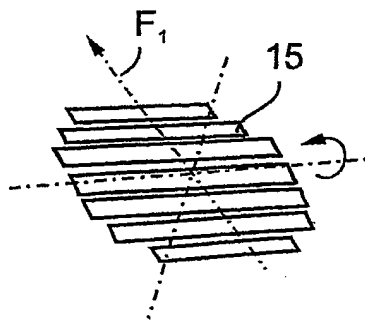


Fig. 4

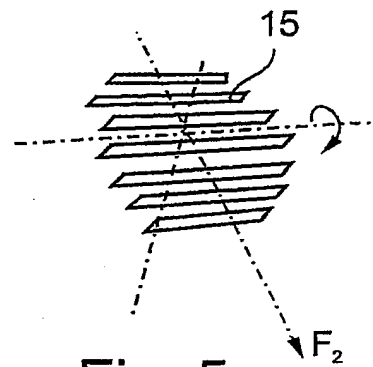


Fig. 5

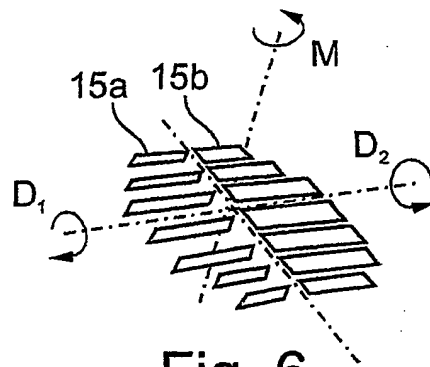


Fig. 6

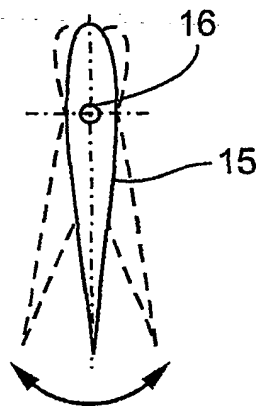


Fig. 7

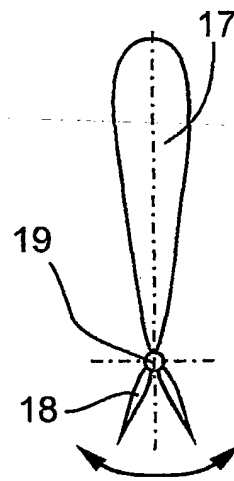


Fig. 8

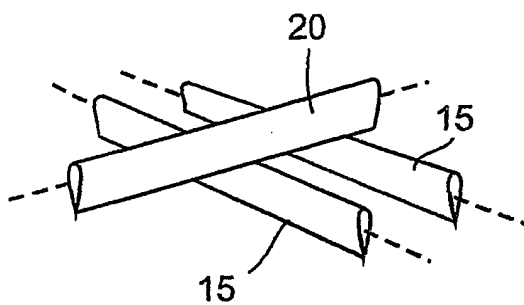


Fig. 9

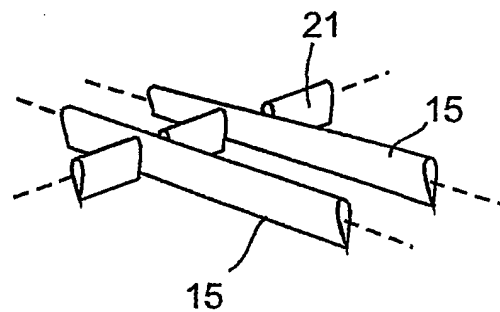


Fig. 10

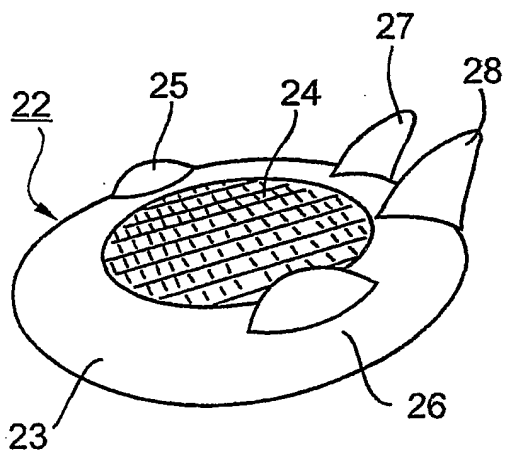


Fig. 11

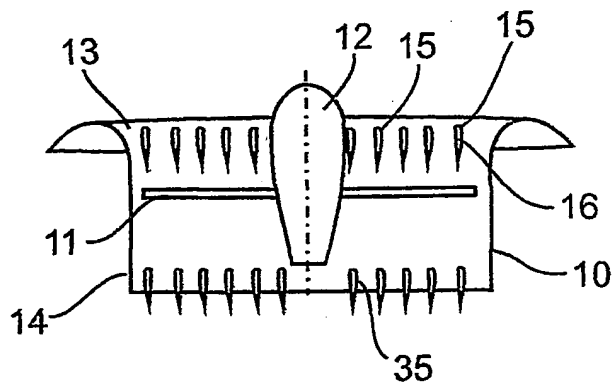


Fig. 12

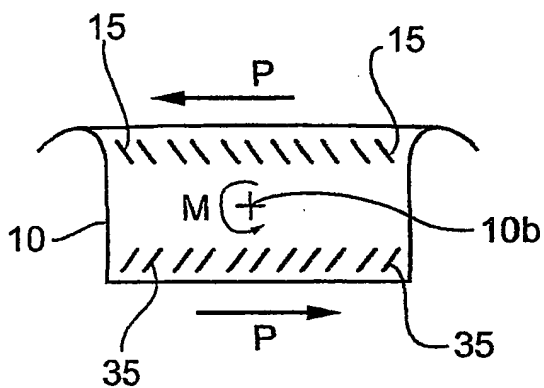


Fig. 13a

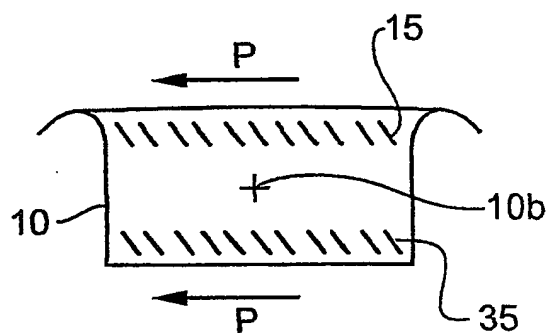


Fig. 13b

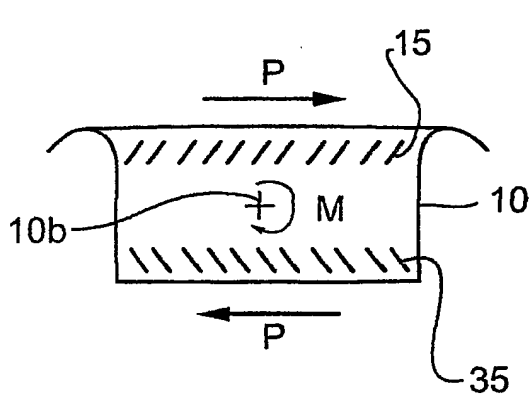


Fig. 13c

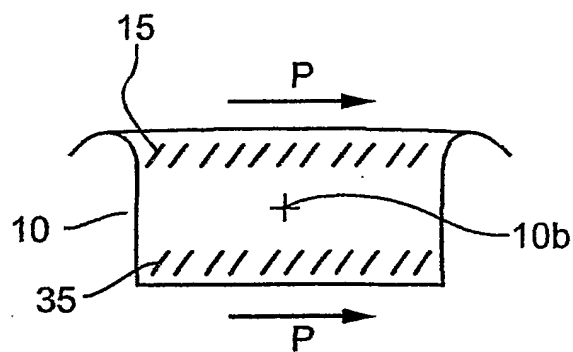


Fig. 13d

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Fig. 14

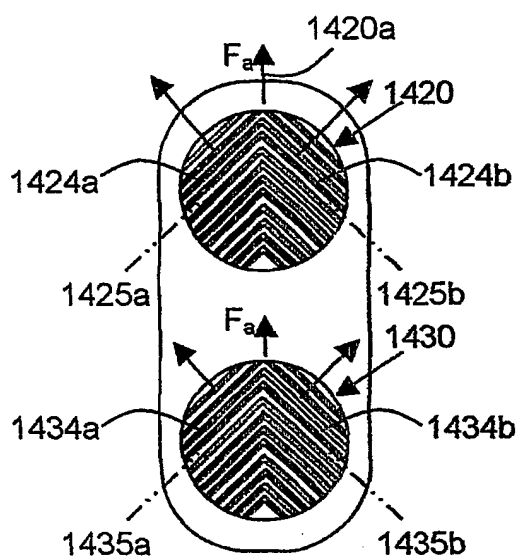
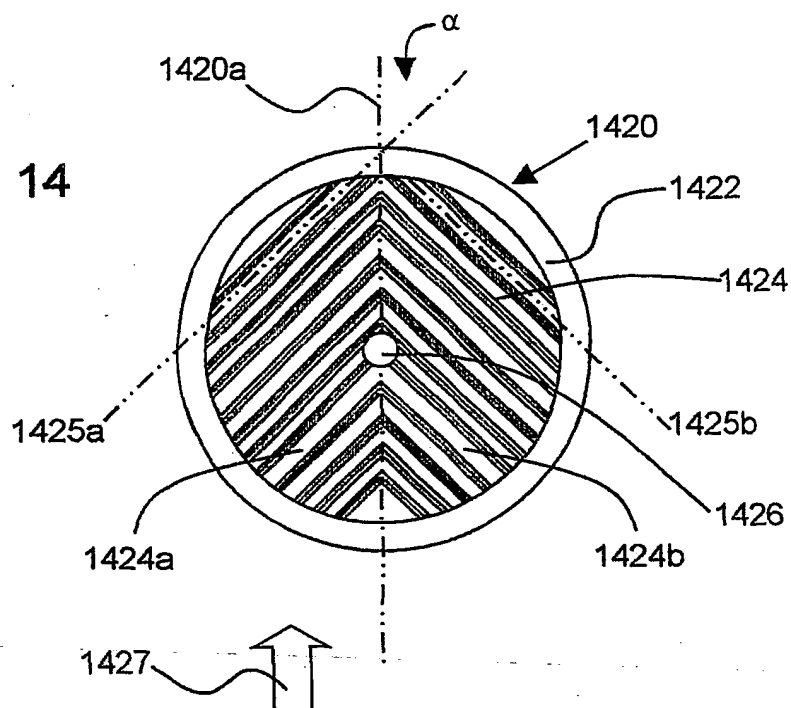


Fig. 15a

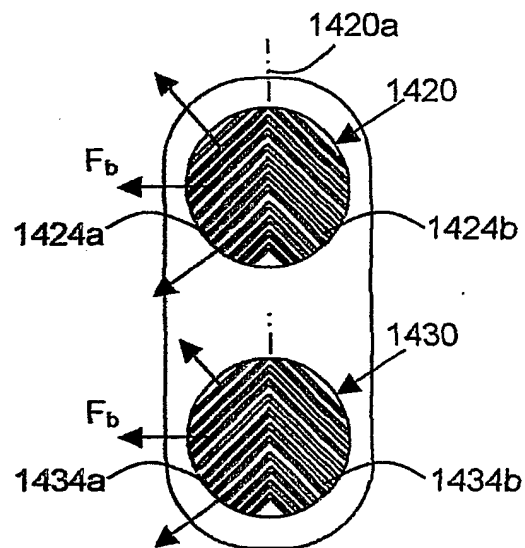


Fig. 15b

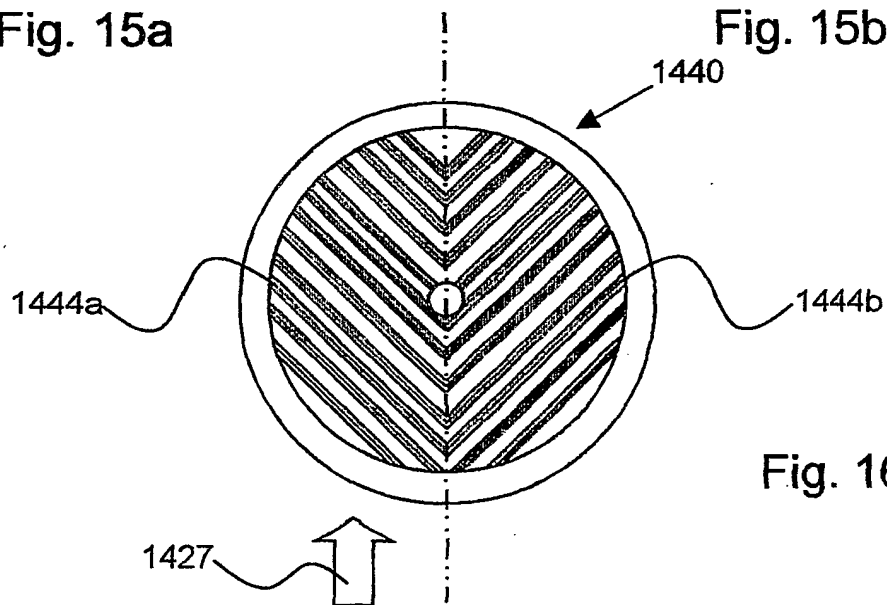


Fig. 16

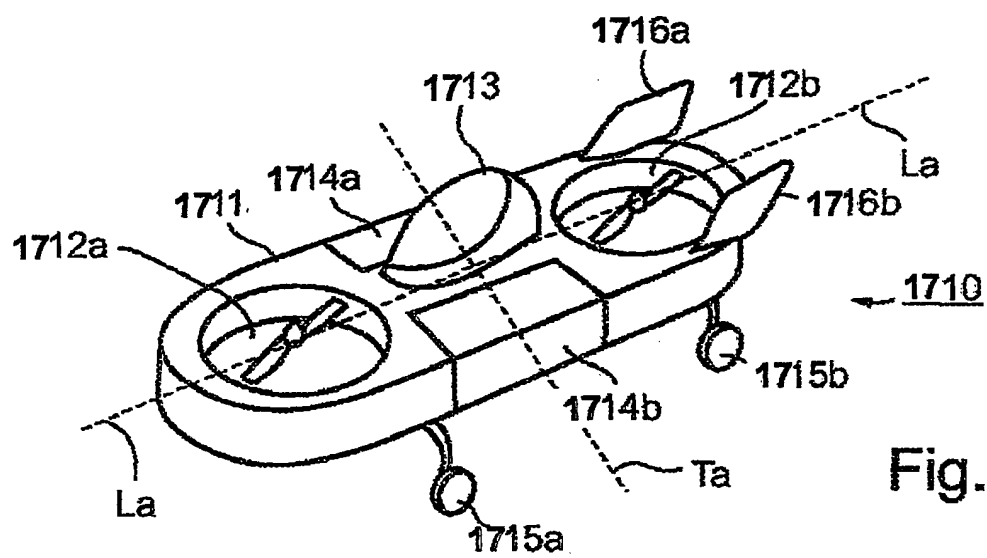


Fig. 17

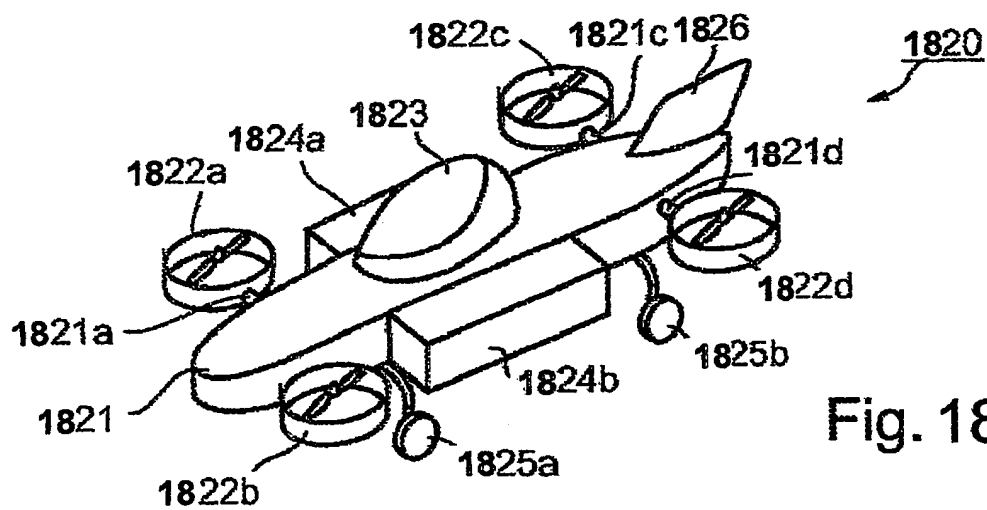


Fig. 18

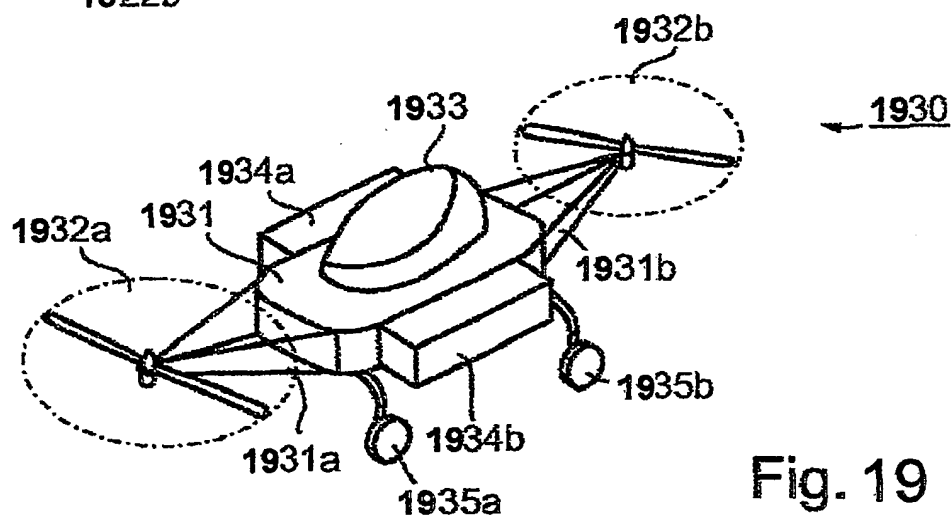


Fig. 19

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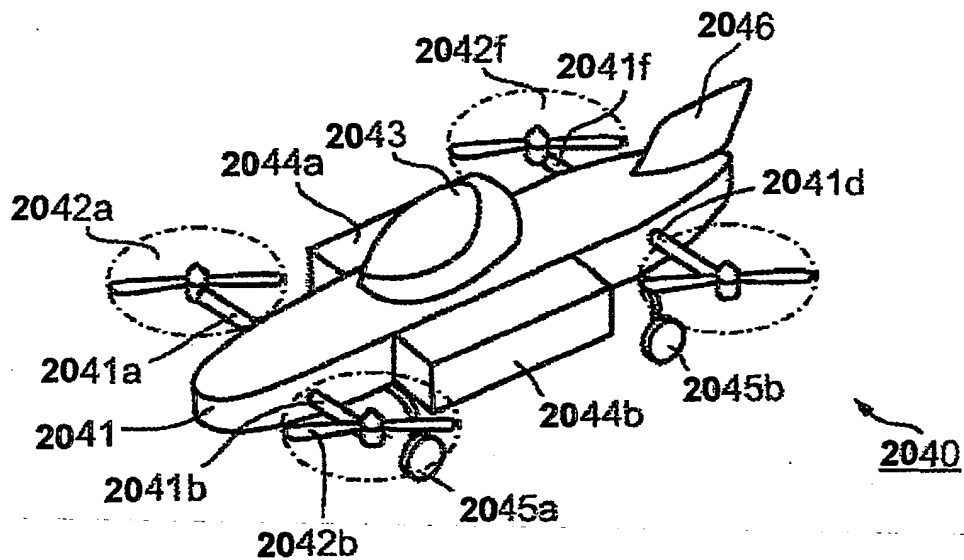


Fig. 20

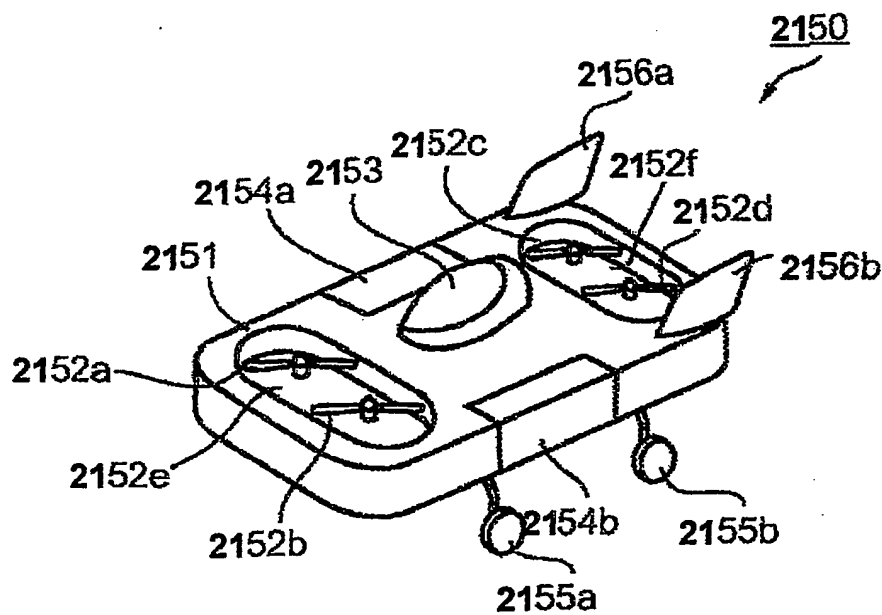


Fig. 21

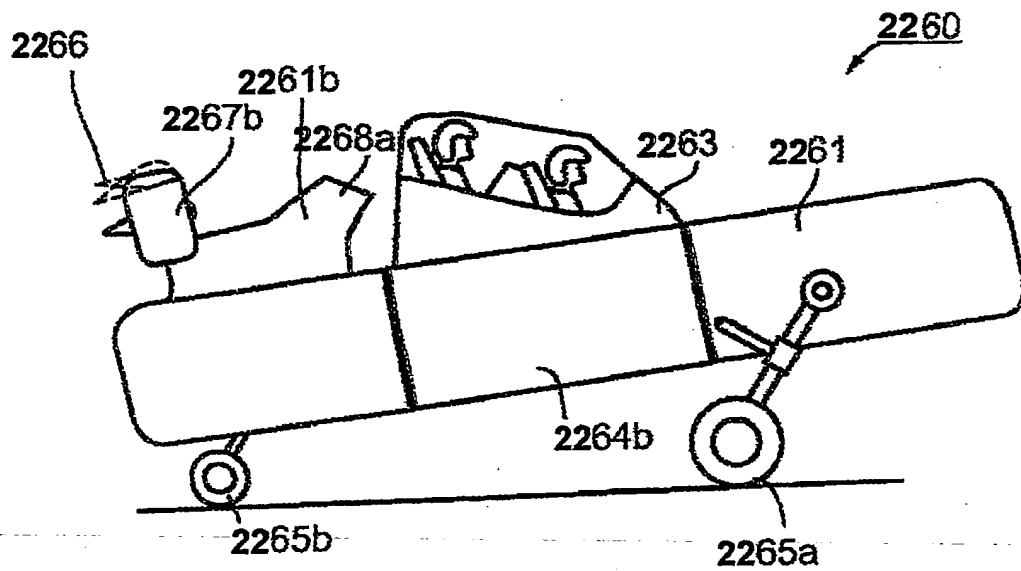


Fig. 22a

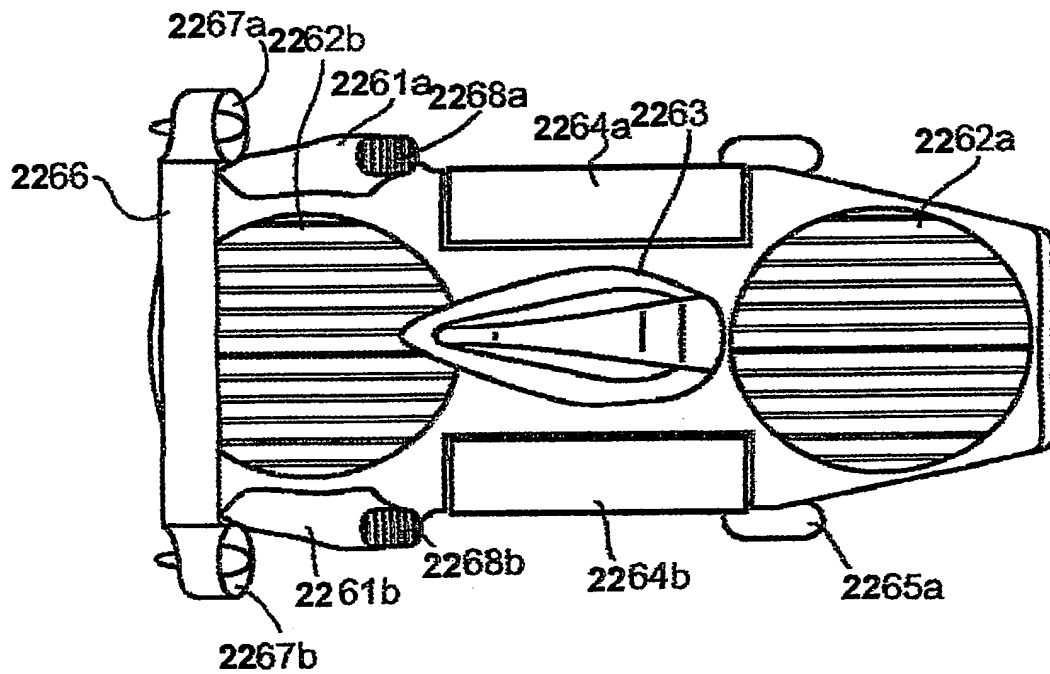


Fig. 22b

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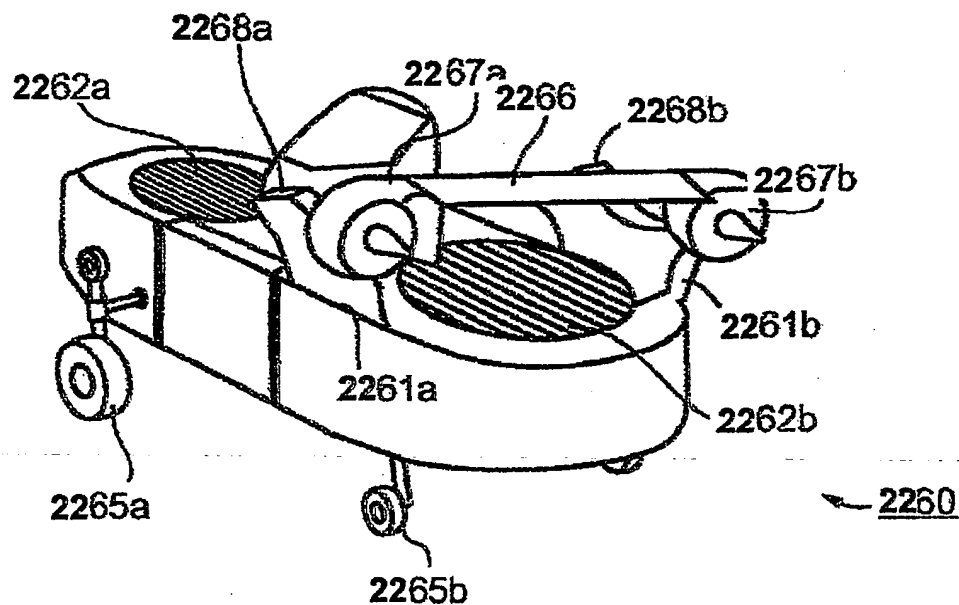


Fig. 22c

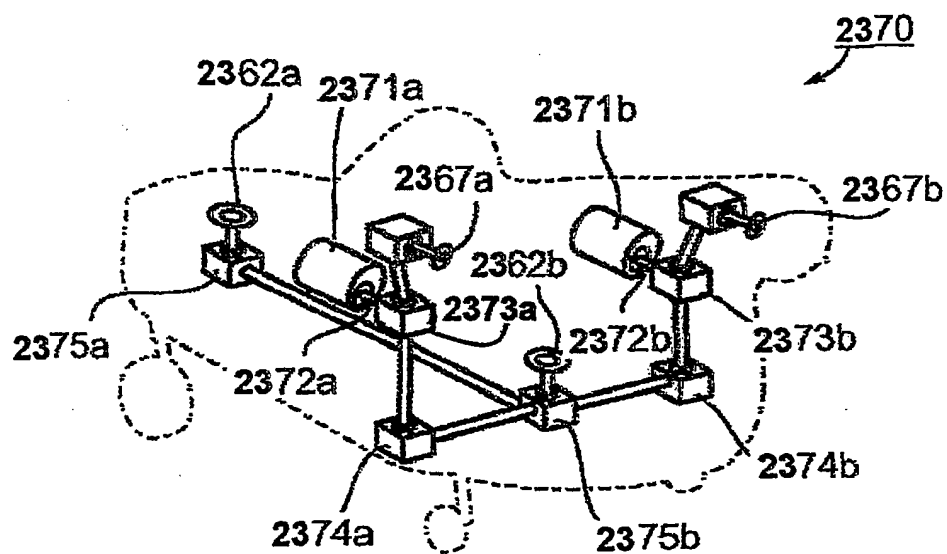
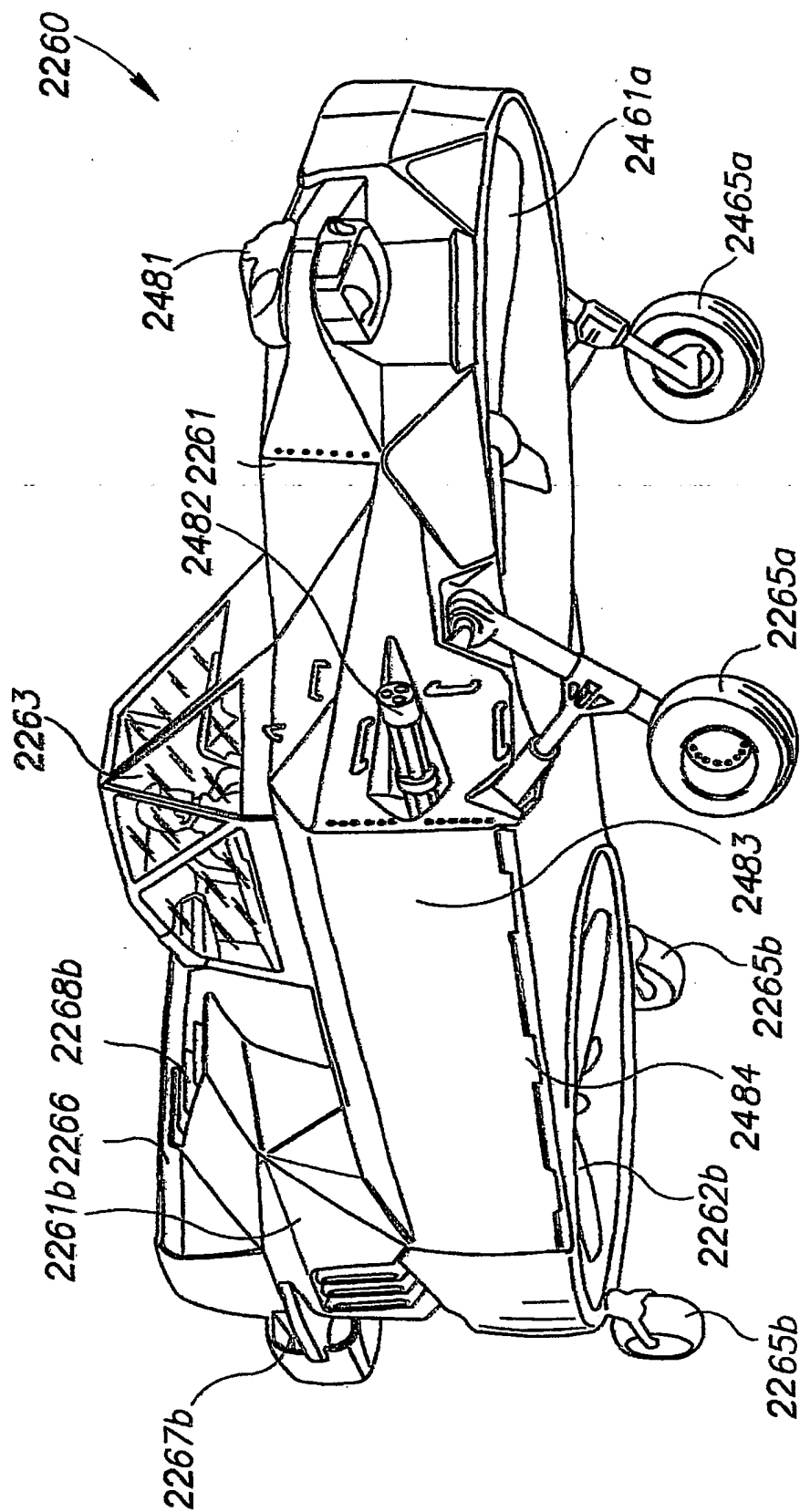


Fig. 23



**Fig. 24**

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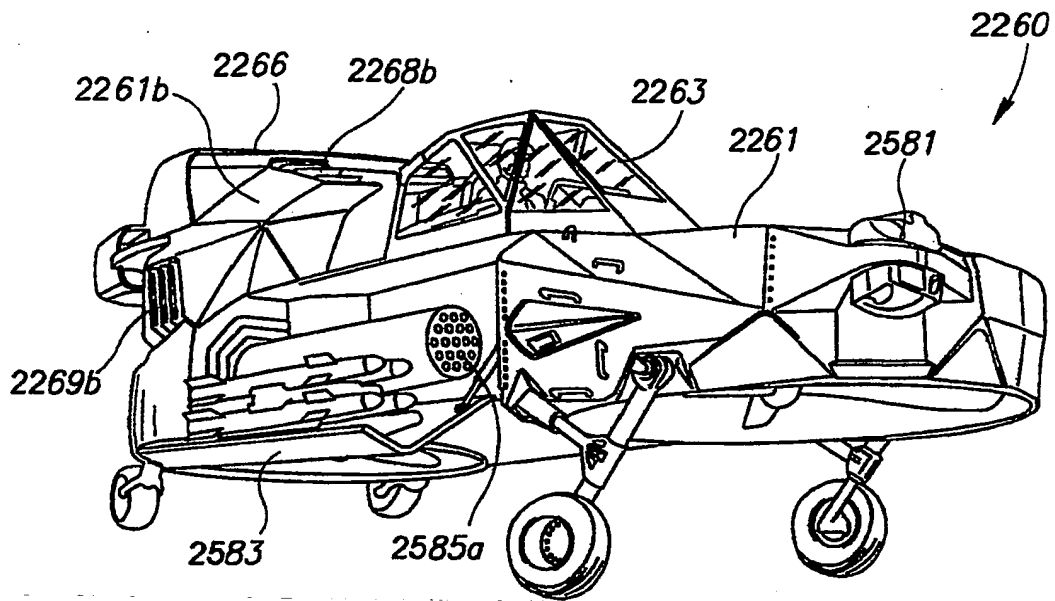


Fig. 25A

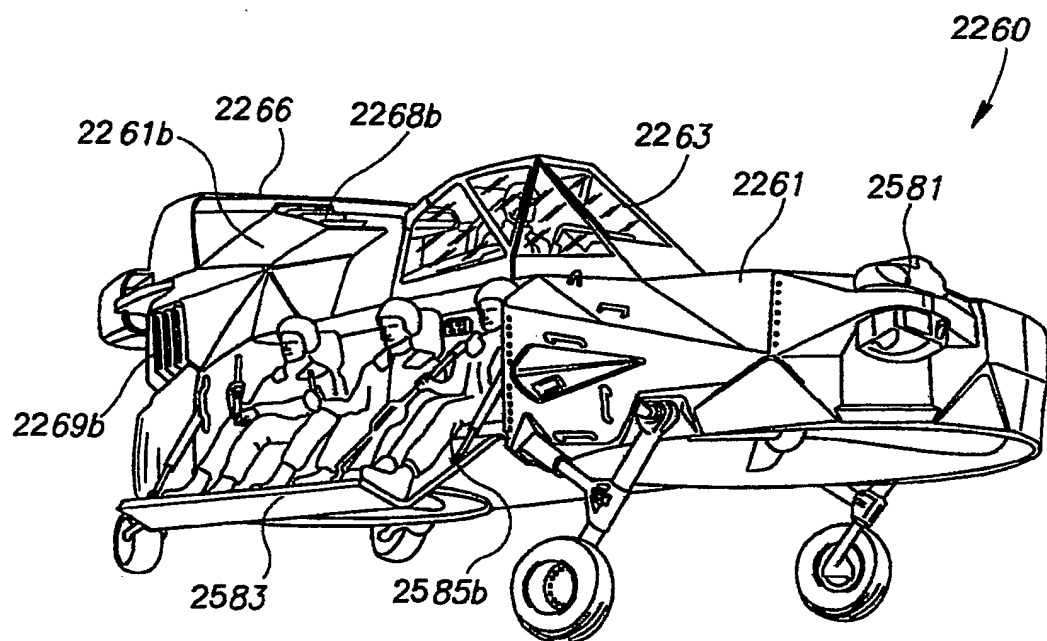


Fig. 25B

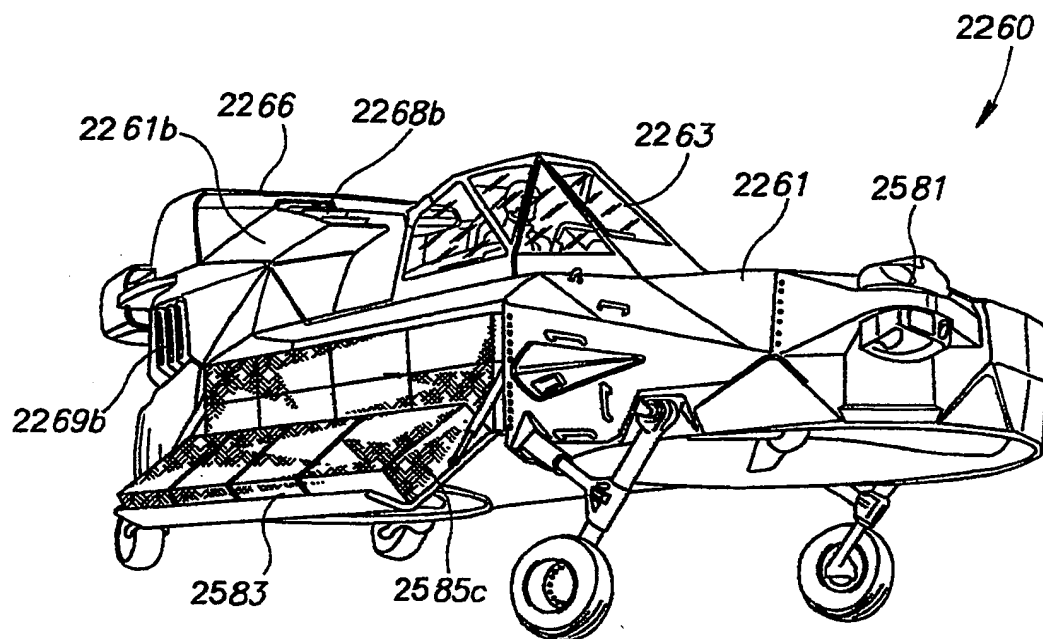


Fig. 25C

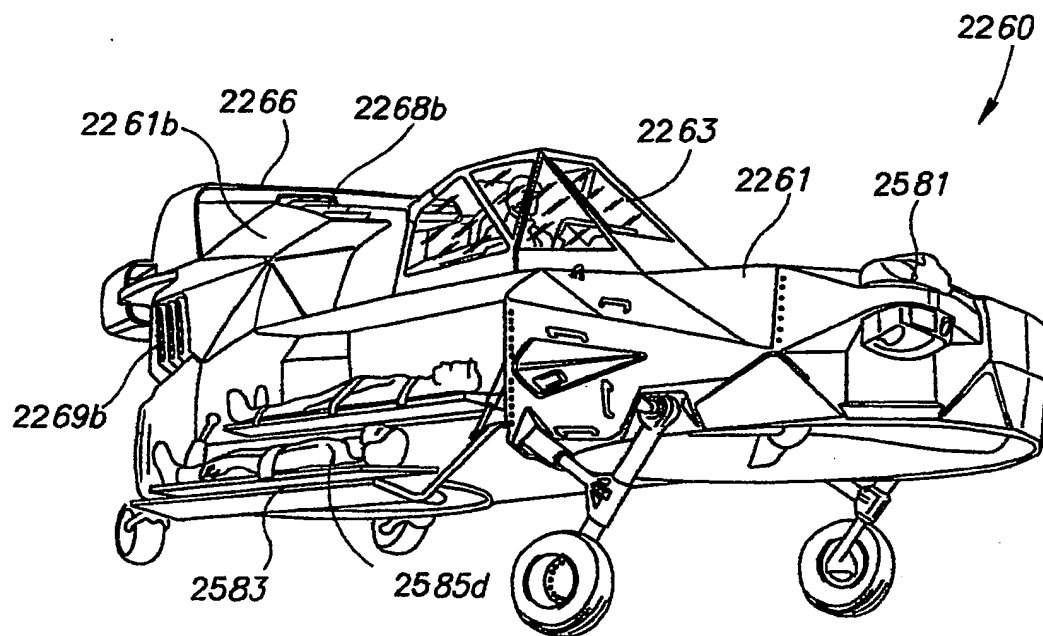


Fig. 25D

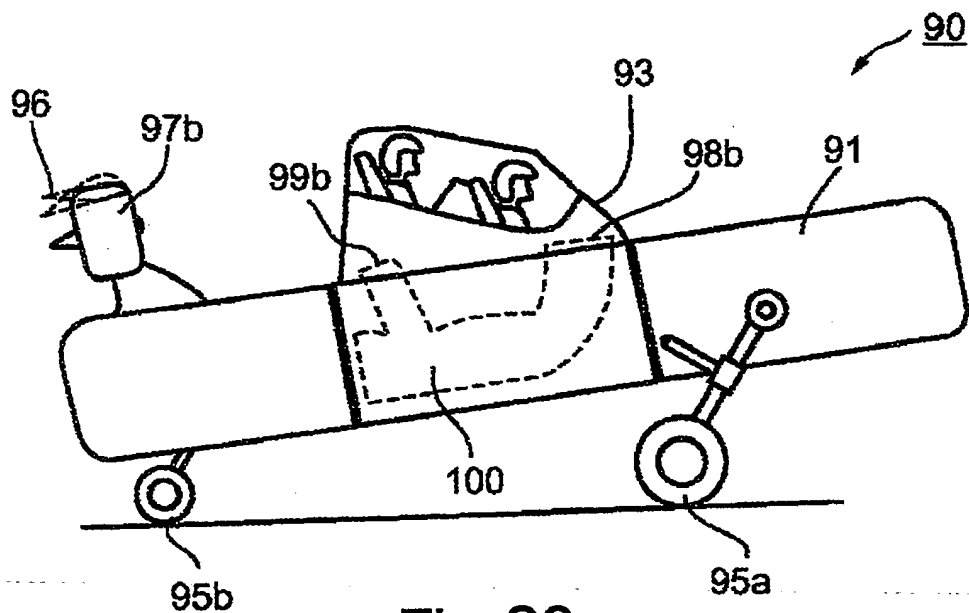


Fig. 26a

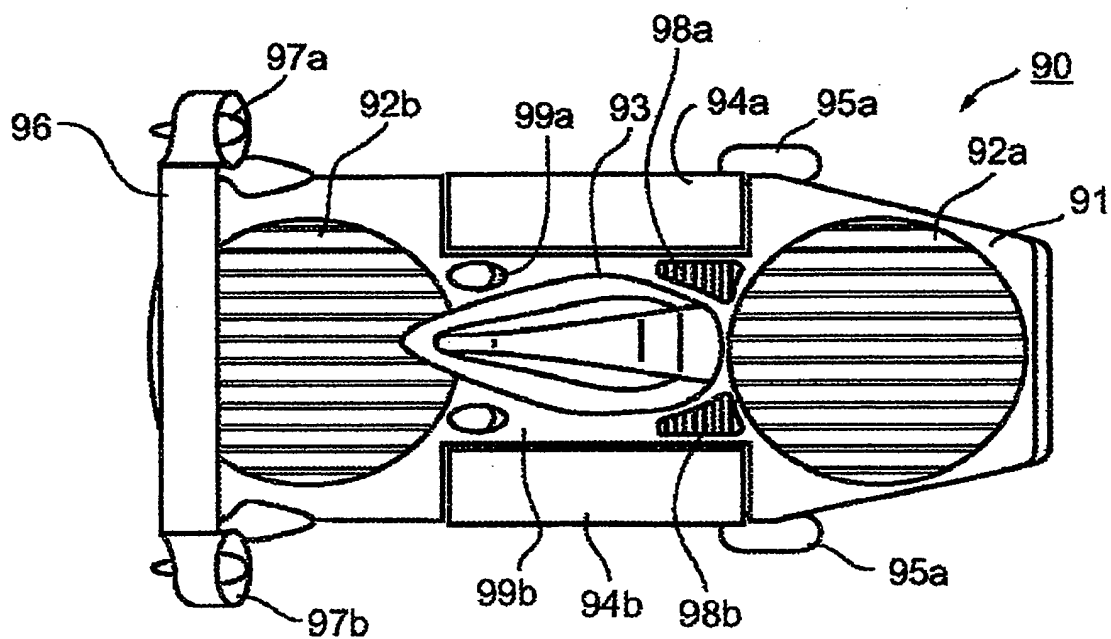


Fig. 26b

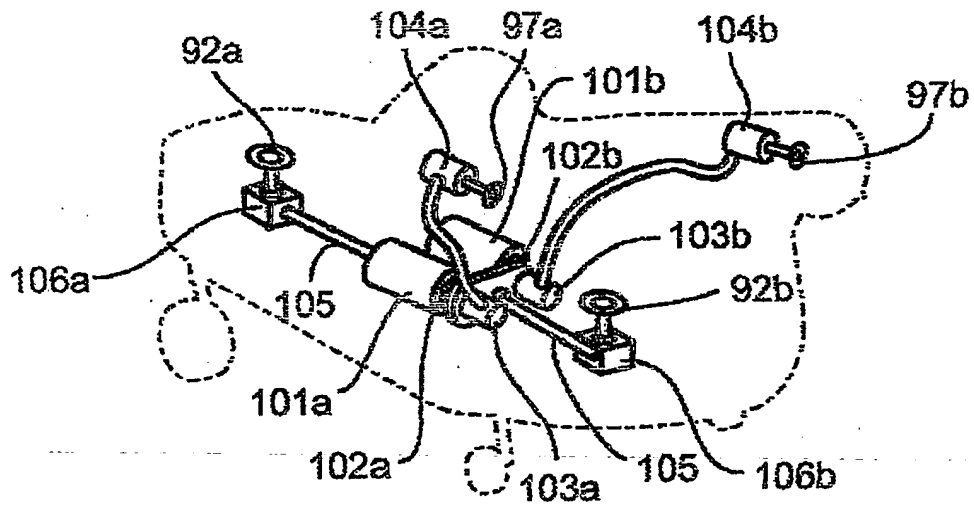


Fig. 27

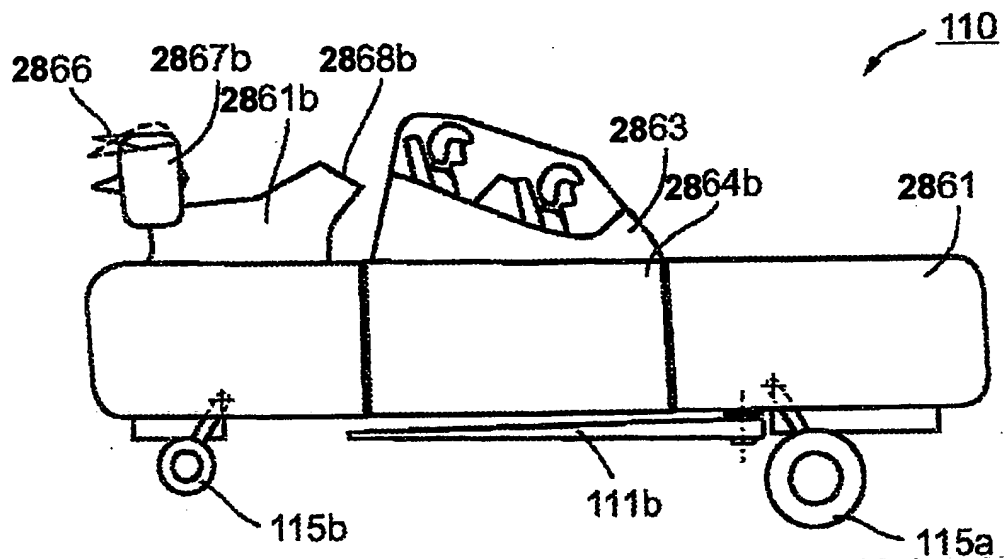


Fig. 28a

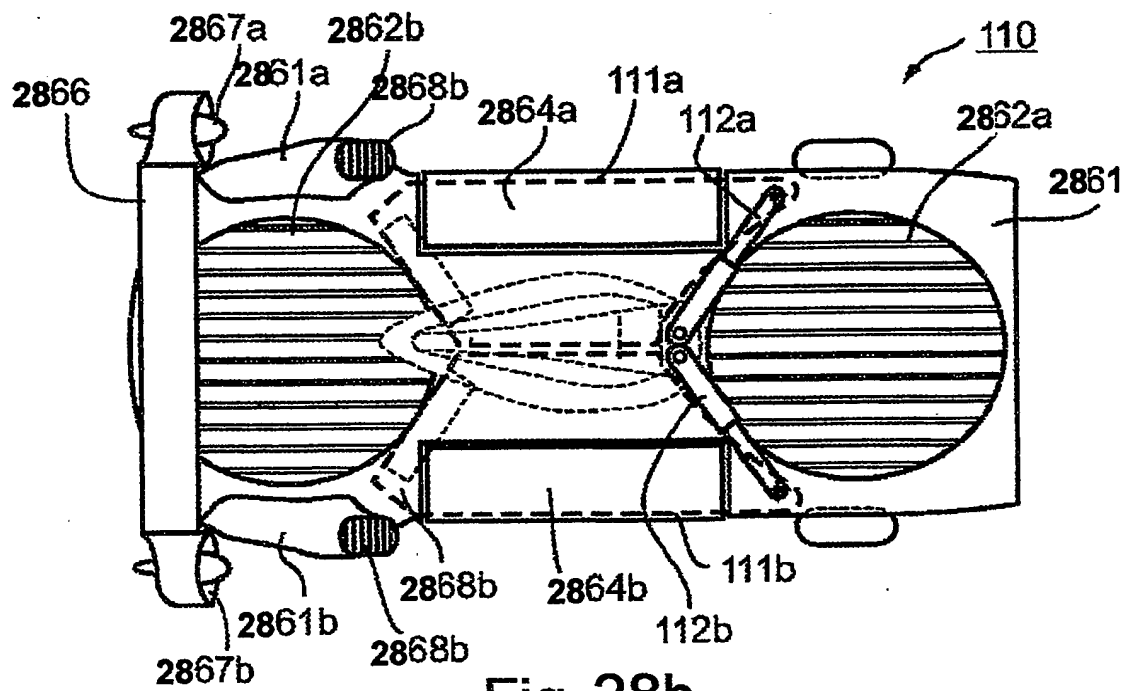


Fig. 28b

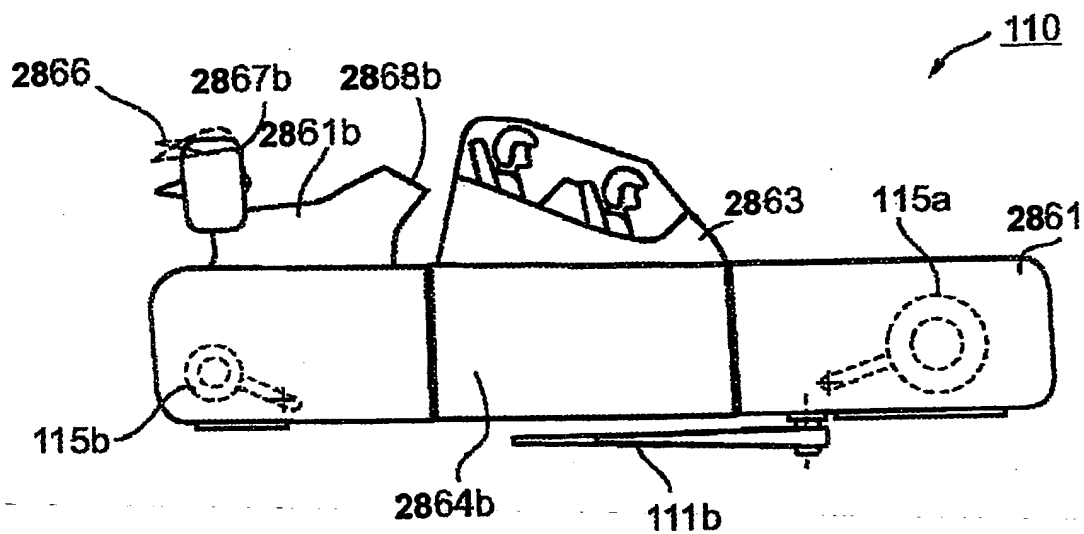


Fig. 28c

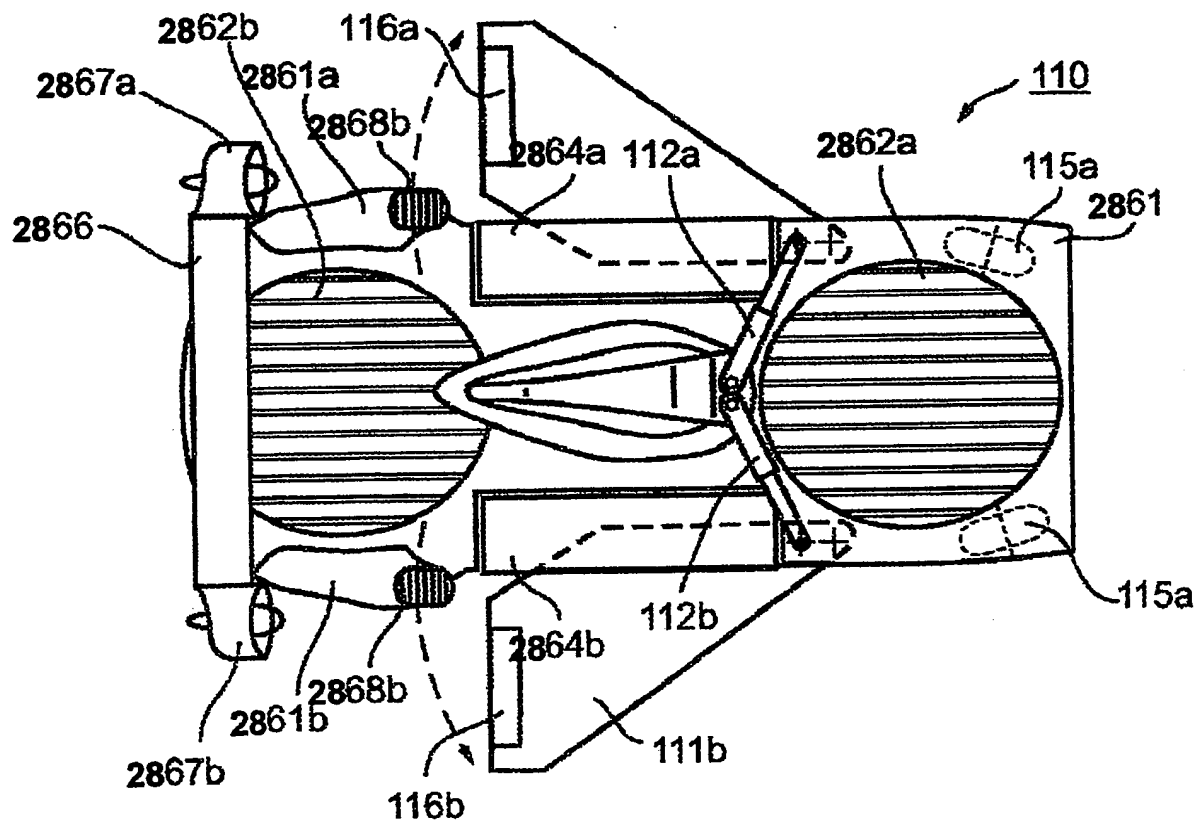


Fig. 28d

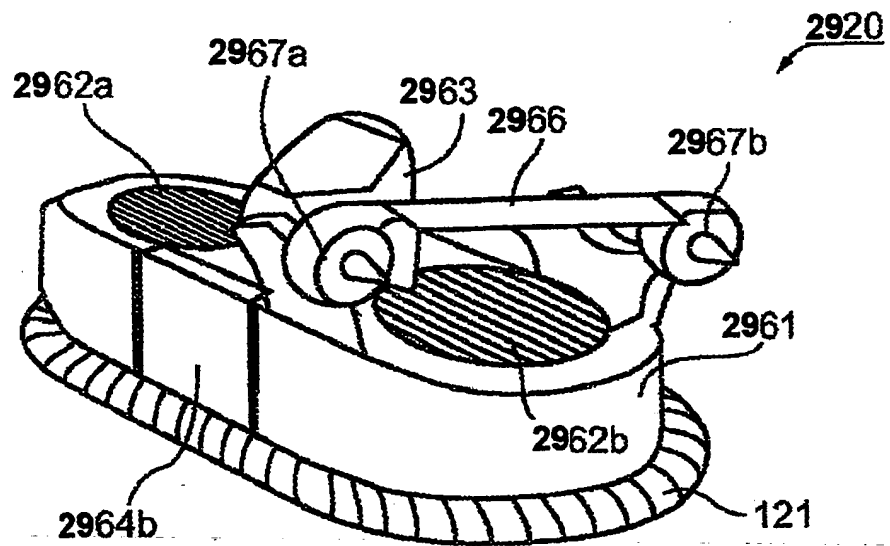


Fig. 29

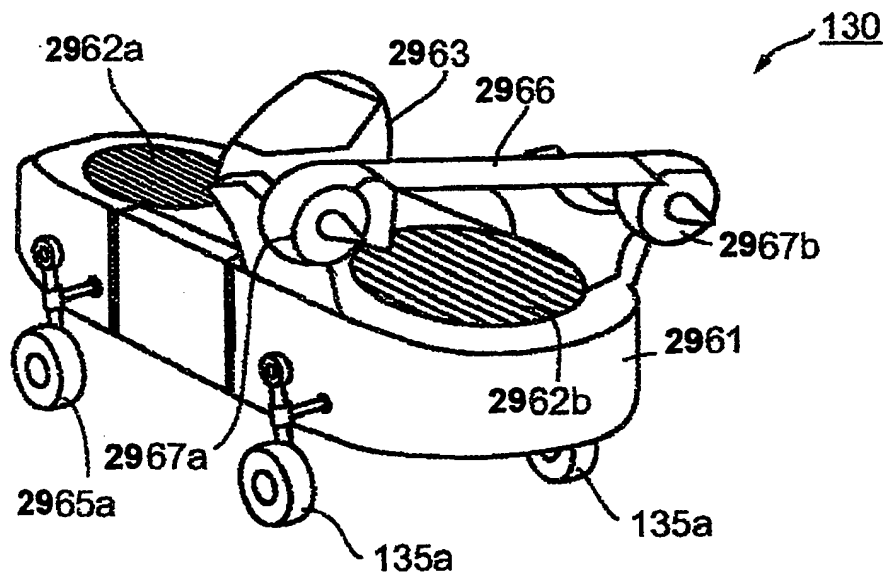


Fig. 30

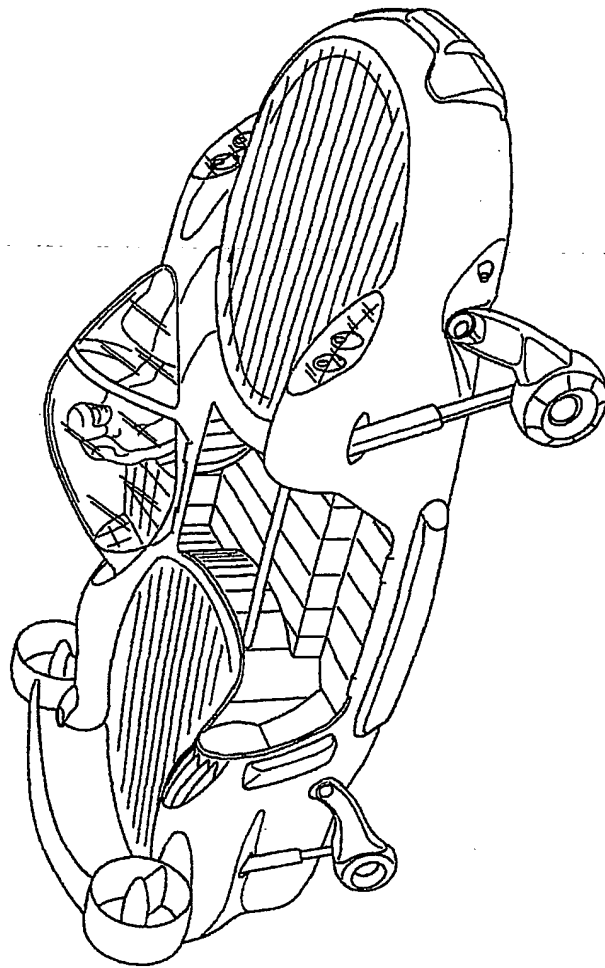


Fig. 31A

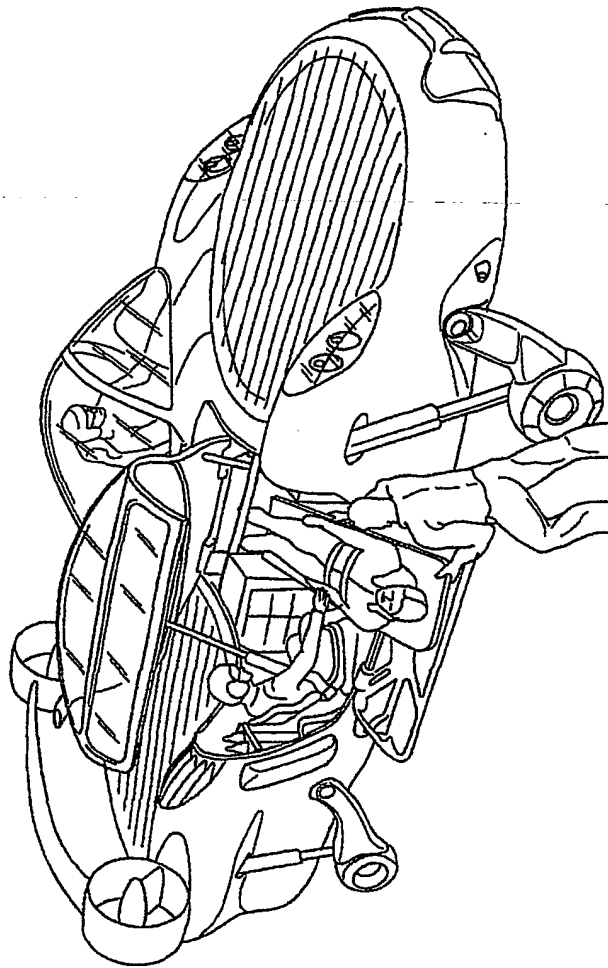


Fig. 31B

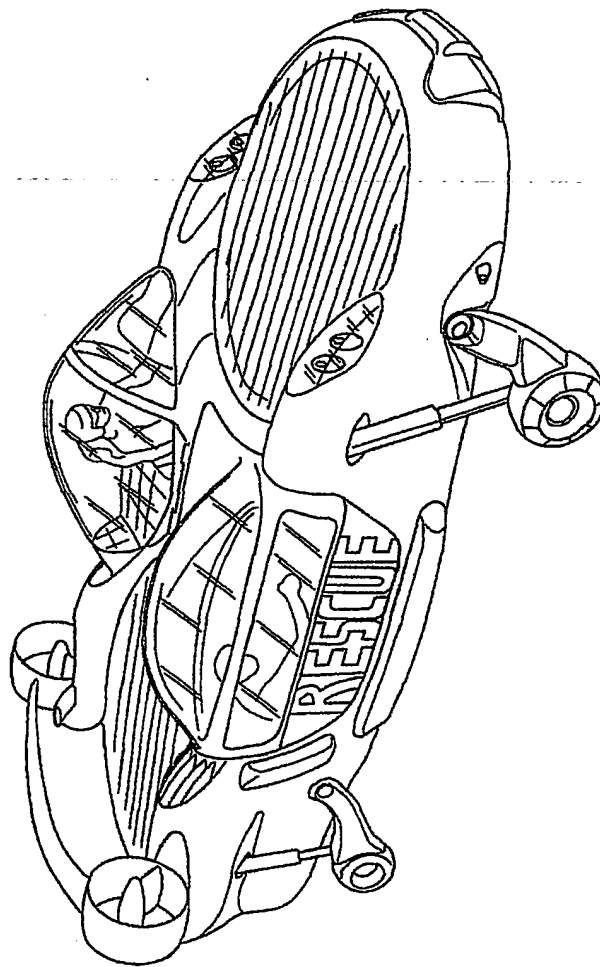


Fig. 31C

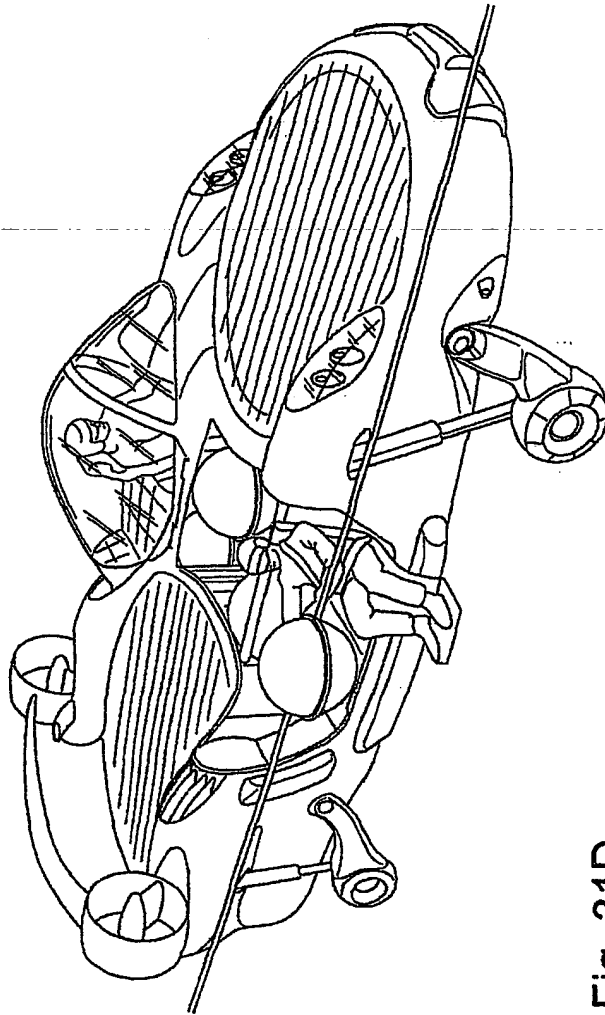


Fig. 31D

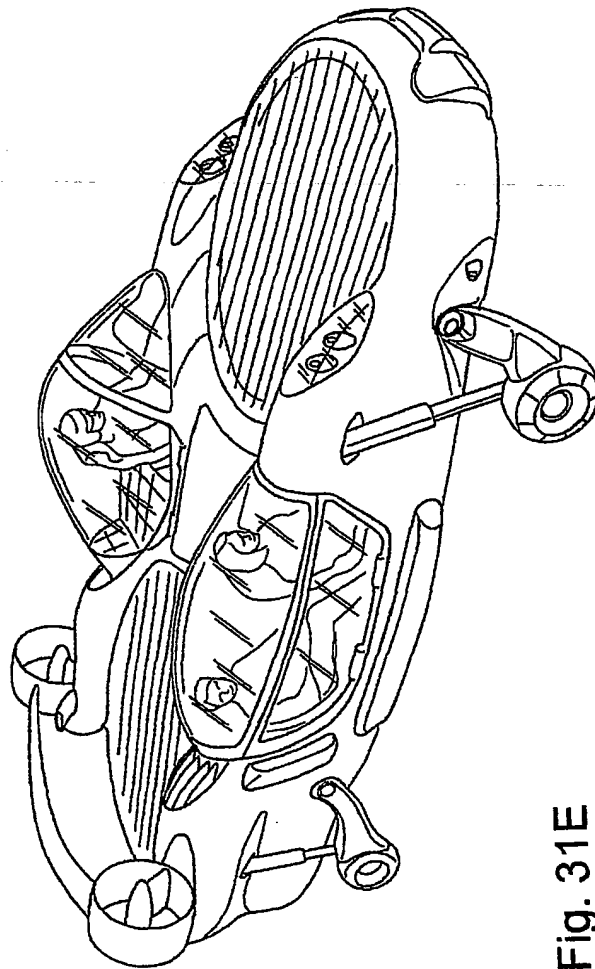


Fig. 31E

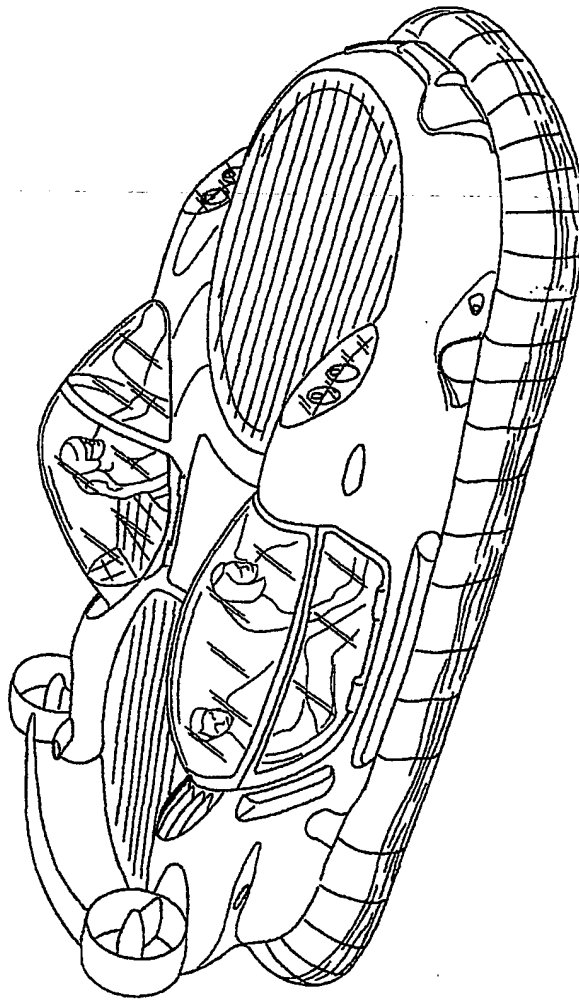


Fig. 32

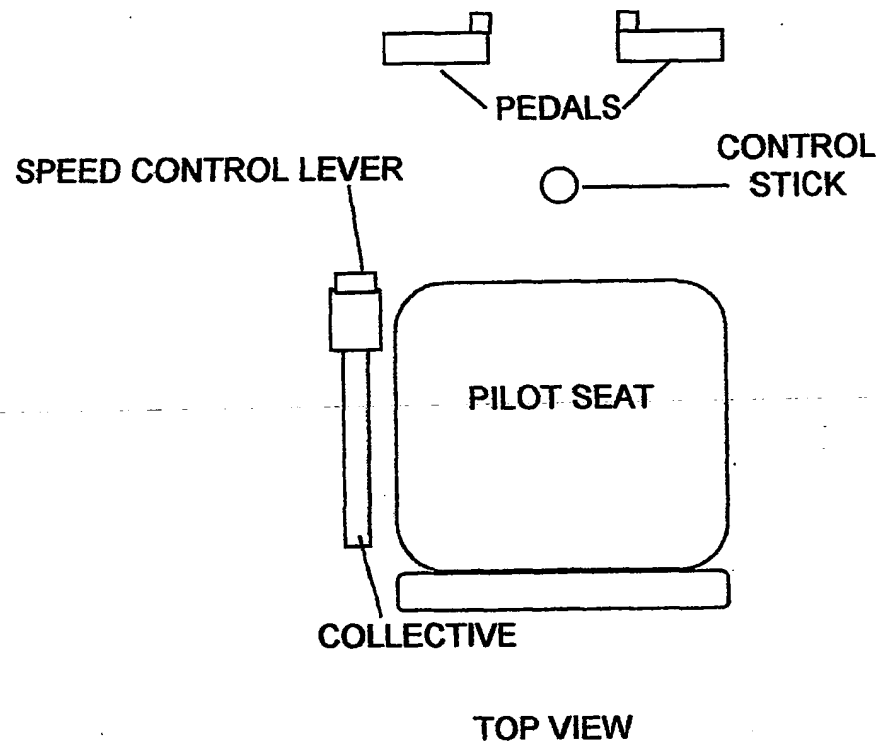
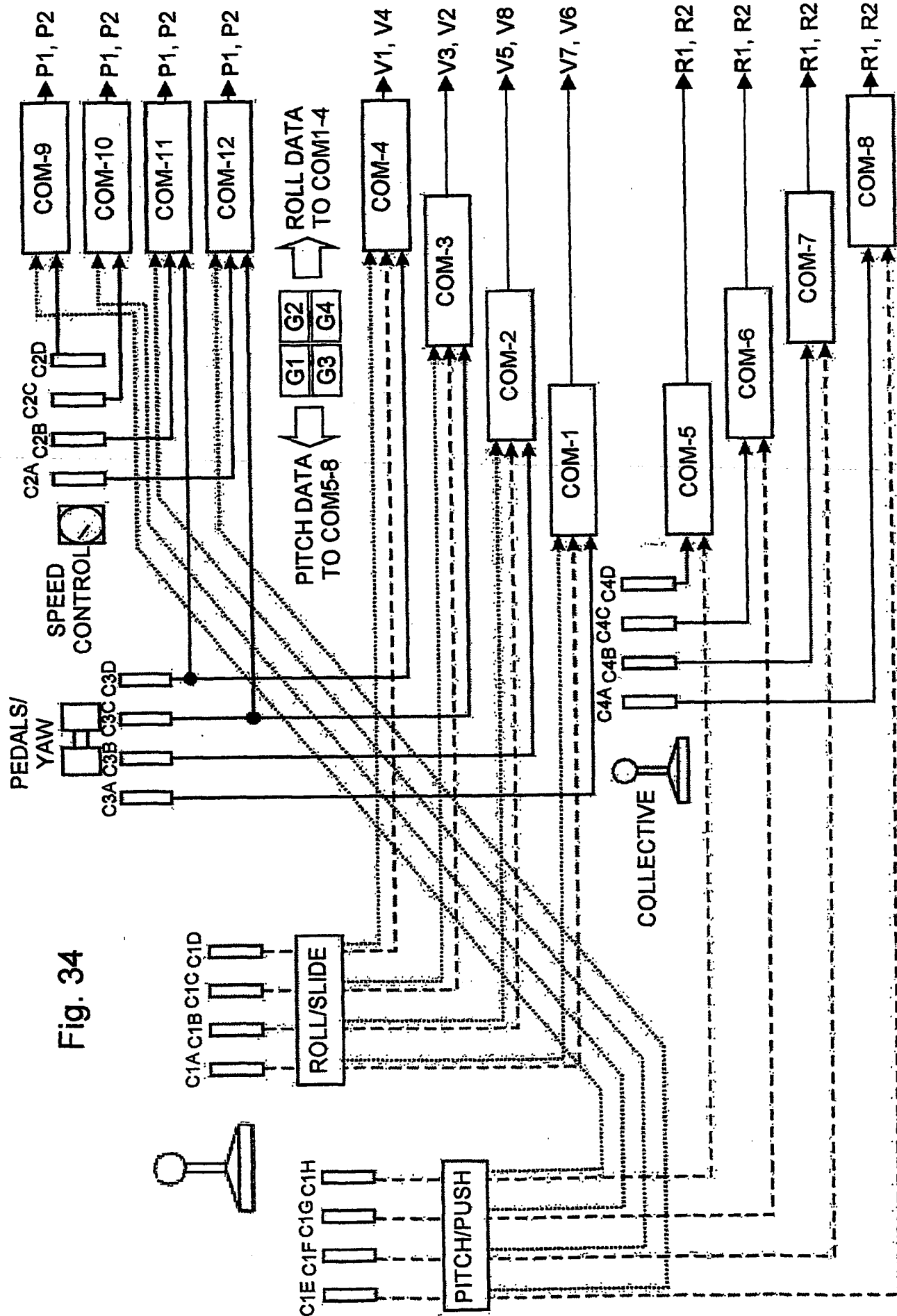


Fig. 33



1.1. Controller	Low Speed Maneuver (LSM)	Forward cruise flight
Stick: Left-Right movement	Produces sideward motion by deflecting all vanes in direction of desired movement	Produces rolling motion by deflecting lower rows of vanes in direction opposite to upper rows of vanes
Stick: Fore-Aft movement	Produces Forward-Aft translation motion by varying pitch angle of blades on both rear mounted pusher propellers	Produces angular pitching motion by varying differentially pitch angle of blades on fore V.S. aft main lift rotors
Collective: Up-Down movement	Produces vehicle altitude change by varying collectively pitch angle of blades on fore and. aft main lift rotors	Produces vehicle altitude change by varying collectively pitch angle of blades on fore and. aft main lift rotors
Speed Controller: Fore-Aft movement	Establishes trimmed Forward-Aft speed by setting pitch angle of blades on both aft mounted pusher propellers	Establishes trimmed Forward-Aft speed by setting pitch angle of blades on both aft mounted pusher propellers
Pedals: Right-Left push (Alternative: Stick grip twist)	Produces angular yawing motion by deflecting differentially forward V.S. aft control vanes, as well as pitch on blades of right V.S. left pusher propellers	Produces angular yawing motion by deflecting differentially forward V.S. aft control vanes, as well as pitch on blades of right V.S. left pusher propellers

Fig. 35

# INTERNATIONAL SEARCH REPORT

International Application No

PCT/IL 03/00786

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 G05D1/00 G05D1/08 B64C13/50

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G05D B64C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 236 583 A (BOEING CO) 16 September 1987 (1987-09-16)	1-5,8,9
Y	column 1, line 20-39 column 3, line 8-17 column 5, line 43-51 column 6, line 37-48 column 7, line 14 -column 8, line 34 column 9, line 1 -column 10, line 28 column 11, line 44-56 figure 1	6,7,10
Y	US 6 431 494 B1 (KINKEAD W DOUGLAS ET AL) 13 August 2002 (2002-08-13) column 1, line 36-55 column 4, line 41-61 figures 1,1A,2	10
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☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

30 January 2004

Date of mailing of the international search report

09/02/2004

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# INTERNATIONAL SEARCH REPORT

International Application No

PCT/IL 03/00786

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	US 3 665 809 A (DARLINGTON RALPH FREDRICK ET AL) 30 May 1972 (1972-05-30) column 2, line 66 -column 3, line 63 figure 1 -----	1-10

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